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(MR-201229)

Comparative Demonstration and Evaluation of Classification Technologies

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14. ABSTRACT
This is Cost and Performance Report for one of a series of the Environmental Security Technology Certification Program (ESTCP) live site demonstrations of advanced geophysical classification (AGC) technologies for Munitions Response (MR). This contract included demonstrations at Camp Ellis Military Range, Illinois; a Remedial Investigation (RI) at Munitions Response Program Site UXO 01 at Marine Corps Air Ground Combat Center (MCAGCC) at Twentynine Palms, California; and AGC of TEMTADS data collected at the Closed Castner Range, Fort Bliss, Texas. During these demonstrations, Arcadis collected dynamic and cued MetalMapper and TEMTADS data and performed AGC on the cued data to transfer the technology to production contractors and determine Arcadis' effectiveness in correctly classifying targets as either targets of interest (TOI)that represent an explosive hazard or non-TOI that don't represent an explosive hazard.

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TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION 1

1.1 BACKGROUND 1

1.2 OBJECTIVES OF THE DEMONSTRATIONS 2

1.3 REGULATORY DRIVERS 2

2.0 TECHNOLOGY 3

2.1 TECHNOLOGY DESCRIPTION 3

2.1.1 Geonics EM61-MK2 3

2.1.2 NRL TEMTADS 3

2.1.3 Geometrics MetalMapper 5

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY 5

2.2.1 EM61-MK2 5

2.2.2 TEMTADS 6

2.2.3 MetalMapper 6

3.0 PERFORMANCE OBJECTIVES 7

4.0 SITE DESCRIPTIONS 15

5.0 TEST DESIGN 17

5.1 CONCEPTUAL EXPERIMENTAL DESIGN 17

5.2 SITE PREPARATION 17

5.3 SYSTEM SPECIFICATION 17

5.3.1 EM61-MK2 17

5.3.2 TEMTADS 17

5.3.3 MetalMapper 17

5.4 DATA COLLECTION 19

5.4.1 EM61-MK2 19

5.4.2 TEMTADS 19

TABLE OF CONTENTS (Continued)

Page

5.4.3 MetalMapper 20
5.4.4 Advanced EMI Sensor Quality Control 20
5.4.5 Data Validation 20
6.0 DATA ANALYSIS AND PRODUCTS 23
6.1 PREPROCESSING 23
6.1.1 EM61-MK2 23
6.1.2 TEMTADS 23
6.1.3 MetalMapper 24
6.2 TARGET SELECTION FOR DETECTION 24
6.2.1 EM61-MK2 24
6.2.2 TEMTADS 25
6.2.3 MetalMapper Peak Picking (MMPP) 25
6.2.4 MetalMapper Dipole Response (MMDR) 25
6.3 PARAMETER ESTIMATES 30
6.4 CLASSIFIER 30
6.5 DATA PRODUCTS 32
7.0 PERFORMANCE ASSESSMENT 33
7.1 DYNAMIC DATA 33
7.1.1 Initial Instrument Function Test 33
7.1.2 Spatial Coverage in Detection Survey 33
7.1.3 Along-line Measurement Spacing 34
7.1.4 Dynamic Detection Performance 34
7.1.5 IVS Repeatability 34
7.1.6 Production Rate 35
7.1.7 Sensor Tx Current 35
7.1.8 Acceptable Sensor Response 35
7.1.9 Valid Position Data (1) – GPS Status 35
7.1.10 Valid Position Data (2) – IMU Status 35
7.2 CUED DATA 36
7.2.1 Initial Sensor Function Test 36
7.2.2 System Functionality 36
7.2.3 Initial IVS Background Measurement 36

TABLE OF CONTENTS (Continued)

Page

7.2.4 Initial IVS Derived Polarizability Accuracy 36
7.2.5 Derived IVS Target Position Accuracy 36
7.2.6 Ongoing IVS Background Measurements 37
7.2.7 Ongoing Derived IVS Polarizabilities Precision 37
7.2.8 Ongoing Derived Target Position Precision (IVS) 37
7.2.9 Cued Interrogation of Anomalies 37
7.2.10 Initial Measurement of Production Area Background Locations 37
7.2.11 Ongoing Production Area Background Measurements 38
7.2.12 Ongoing Instrument Function Tests 38
7.2.13 Tx Current Levels 38
7.2.14 Production Rate 38
7.2.15 Sensor Response within Valid Range 38
7.2.16 Confirm all Background Measurements are Valid 38
7.2.17 Confirm all Measurements have an Applicable Background 39
7.2.18 Confirm GPS Precision 39
7.2.19 Valid Position Data (1) – GPS Status Flag 39
7.2.20 Valid Position Data (2) – IMU 39
7.2.21 Confirm Inversion Model Supports Classification (1 of 3) – Fit Coherence 39
7.2.22 Confirm Inversion Model Supports Classification (2 of 3) – Fit Location 40
7.2.23 Confirm Inversion Model Supports Classification (3 of 3) – Fit Location 40
7.2.24 Confirm Derived Features Match Ground Truth (1 of 2) – Fit Location 40
7.2.25 Confirm Derived Features Match Ground Truth (2 of 2) – AGC results 40
7.2.26 Validation of TOI/non-TOI Thresholds 41
7.2.27 Maximize Correct Classification of non-TOI 44
7.2.28 Minimize Number of Anomalies that Cannot be Analyzed 44
7.2.29 Correct Estimation of Target Parameters 45

8.0 COST ASSESSMENT 47
8.1 COST MODEL 47
8.2 COST DRIVERS 47
8.3 COST BENEFIT 51

9.0 IMPLEMENTION ISSUES 53
9.1 FIELD IMPLEMENTATION ISSUES 53

TABLE OF CONTENTS (Continued)

Page

9.2 DATA PROCESSING AND AGC IMPLEMENTATION ISSUES 54

10.0 REFERENCES 55

APPENDIX A POINTS OF CONTACT A-1

LIST OF FIGURES

Page

Figure 2-1. Geonics EM61-MK2 at 29 Palms 4

Figure 2-2. TEMTADS at 29 Palms 4

Figure 2-3. Geometrics MetalMapper at 29 Palms 5

Figure 6-1. 29 Palms Dynamic EM61-MK2 Data 26

Figure 6-2. CEMR Partial Dynamic TEMTADS Data within Target Area 27

Figure 6-3. 29 Palms Dynamic MMPP Data Example 28

Figure 6-4. 29 Palms Dynamic MMDR Data Example 29

Figure 6-5. MMDR Target Selection at 29 Palms 31

LIST OF TABLES

Page

Table 2-1. Technologies Used on Live Site Demonstrations 3

Table 3-1. Dynamic Performance Metrics and Results for Arcadis' Live Site Demonstrations ... 8

Table 3-2. Cued Performance Metrics and Results for Arcadis' Live Site Demonstrations 9

Table 4-1. Live Site Demonstrations 15

Table 5-1. Project Details for Demonstration Sites 18

Table 6-1. Anomaly Selection Thresholds and Rationale for Live Site Demonstrations 24

Table 6-2. Ranked Anomaly List Details 32

Table 7-1. AGC Approach at CCR for Analysts 1 and 2 43

Table 7-2. Decision Statistic Comparisons for Analysts 1 and 2 44

Table 8-1. Details of Costs Tracked during Arcadis' Live Site Demonstrations 48

Table 8-2. AGC Cost Evaluation 52

ACRONYMS AND ABBREVIATIONS

29 Palms	Marine Corps Air Ground Combat Center Twentynine Palms
A	Amperage
Acorn	Acorn Science and Innovation, Inc.
AGC	Advanced Geophysical Classification
Arcadis	Arcadis US, Inc.
β	polarizability
bgs	below ground surface
BSI	Blind Seed Item
CCR	Closed Castner Range
CEMR	Former Camp Ellis Military Range
cm	centimeter
CPU	Central processing unit
CSV	Comma Separated Values
DGM	Digital Geophysical Mapping
DGPS	Differential Global Positioning System
DoD	Department of Defense
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
ft	feet
GCMR-QAPP	Geophysical classification for munitions response-quality assurance project plan
GDB	Geosoft Database
GPS	Global Positioning System
GSV	Geophysical Systems Verification
HE	High Explosive
Hz	Hertz
IAW	In Accordance With
IDL	Interactive Data Language
IMU	Inertial Measurement Unit
in	inch
ISO	Industry Standard Object
ISS	Informed Source Selection
IVS	Instrument Verification Strip

m	meter
MCGACC	Marine Corps Air Ground Combat Center
MD	Munitions Debris
MEC	Munitions and Explosives of Concern
MetalMapper	MetalMapper™
mm	millimeter
MMDR	MetalMapper Dipole Response
MMPP	MetalMapper Peak Picking
MMRP	Military Munitions Response Program
MP	Man Portable
MQO	Measurement Quality Objective
MRS	Munitions Response Site
ms	milliseconds
mV	milliVolts
NA	Not Applicable
NRL	Naval Research Laboratory
OSDA	Office of the Under Secretary of Defense for Acquisition
PI	Principal Investigator
PP	Peak picking
PVC	Polyvinyl Chloride
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
RI	Remedial Investigation
ROC	Receiver Operating Characteristics
RPM	Remedial Program Manager
RTK	Real Time Kinematic
Rx	Receiver
TEMTADS	Time-domain Electromagnetic Multi-Sensor Towed Array Detection System 2x2
TOI	Target of Interest
Tx	Transmitter
URS	URS Group, Inc.
U.S.	United States
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
V	Volt
WP	White Phosphorous

EXECUTIVE SUMMARY

The Environmental Security Technology Certification Program (ESTCP) contracted Arcadis United States (U.S.), Inc., (Arcadis) to complete demonstrations of Advanced Geophysical Classification (AGC) technologies at three (3) Munitions Response Sites (MRSs):

1. Former Camp Ellis Military Range (CEMR) – 2013
2. Marine Corps Air Ground Combat Center (29 Palms) Twentynine Palms, California – 2014, 2015
3. Closed Castner Range (CCR) at Fort Bliss, Texas – 2016.

This report is a summary of cost and performance results from those demonstration sites. Full project information for each demonstration site is in each respective report, all of which have been previously submitted to ESTCP.

OBJECTIVES OF THE DEMONSTRATIONS

The objectives of these demonstrations were to determine the effectiveness of the MetalMapper™ (MetalMapper) and Time-domain Electromagnetic Multi-Sensor Towed Array Detection System 2x2 (TEMTADS) advanced Electromagnetic Induction (EMI) sensors and advanced software in performing AGC to minimize the number of intrusive investigations while still recovering all of the Targets of Interest (TOIs), which include Munitions and Explosives of Concern (MEC) and Industry Standard Objects (ISOs) used for blind seeding purposes. An additional objective was to assist in evaluating the feasibility of transitioning these technologies from federal research models to commercial production models.

TECHNOLOGY DESCRIPTION

A total of three (3) separate instruments were utilized at the various demonstrations noted above:

- Geonics EM61-MK2 (CEMR and 29 Palms),
- Naval Research Laboratory (NRL) TEMTADS (CEMR, 29 Palms, CCR), and
- Geometrics MetalMapper (CEMR, 29 Palms).

All three instruments are time-domain, EMI sensors. Each of the sensors transmits a current through an electrical loop, which induces a primary magnetic field that magnetizes buried (or surface) objects. Turning off the transmit current causes an abrupt change in the magnetic field, which in turn excites eddy currents within the metallic object. These eddy currents then decay as a function of time and are recorded at various time gate measurements. While the basic operational theory of each of these instruments is essentially the same, the size and number of transmitters and receiver coils, as well as time gate measurements, all vary from instrument to instrument. Each of these instruments can be utilized in either dynamic mode, but only the MetalMapper and TEMTADS can be used in cued, or static, mode. The position of each is controlled using a Real-Time Kinematic (RTK) precision Differential Global Positioning System (DGPS) with sub-decimeter accuracy.

DEMONSTRATION RESULTS

These site demonstrations showed that both the MetalMapper and TEMTADS, used in conjunction with the Geosoft Oasis Montaj's UX-Analyze Advanced software module, were effective in distinguishing TOI from non-TOI, which include munitions debris and other debris, thus reducing the number of potential intrusive investigations. Additionally, each subsequent site demonstration revealed improvements in each advanced sensor, each leading closer to the feasibility of commercial production of said sensors.

IMPLEMENTATION ISSUES

To facilitate industry-wide implementation of AGC technology, three key factors need to be addressed: cost, mobility, and reliability. Implementation issues encountered during this demonstration include: 1) the inability of the MetalMapper to efficiently work in randomized grids during a remedial investigation, 2) the MetalMapper tow vehicle digging into unconsolidated sand when turning within a production area, which could have represented an explosive safety hazard, 3) the low height of the TEMTADS, which got caught on short corn stalks sticking out of the ground during dynamic data collection, and 4) the non-repeatable background data at CCR, which decreased the efficiently of the AGC process.

1.0 INTRODUCTION

1.1 BACKGROUND

The Environmental Security Technology Certification Program (ESTCP) contracted Arcadis United States (U.S.), Inc., (Arcadis) to complete demonstrations of Advanced Geophysical Classification (AGC) technologies to include the use of advanced Electromagnetic Induction (EMI) sensors and physics-based models to classify anomalies as either Targets of Interest (TOI) or non-TOI. Arcadis performed demonstrations at the following three (3) Munitions Response Sites (MRSs):

1. **Former Camp Ellis Military Range (CEMR), Illinois:** Arcadis performed a comparative study by collecting Digital Geophysical Mapping (DGM) data with the EM61-MK2, dynamic data with the MetalMapper™ (MetalMapper) and Time-domain Electromagnetic Multi-Sensor Towed Array Detection System 2x2 (TEMTADS), and cued data with the MetalMapper and TEMTADS. Arcadis was the Principal Investigator (PI) and performed data collection, data quality control (QC) and performed AGC on the cued MetalMapper and TEMTADS data. Geometrics provided training for the Arcadis personnel on the use of the MetalMapper and the Naval Research Laboratory (NRL) provided training on the TEMTADS. NAEVA Geophysics, Inc., assisted with field data collection and QC for portions of the data collected and Acorn Science and Innovation, Inc. (Acorn) provided technical guidance in the use of Geosoft Oasis Montaj's UX-Analyze Advanced module to perform AGC (Arcadis, 2014).
2. **Marine Corps Air Ground Combat Center Twentynine Palms (29 Palms), California:** Arcadis demonstrated the ability to use AGC during a Remedial Investigation (RI) when the number of intrusive investigations was limited to approximately 40 total targets. During this demonstration, Arcadis performed dynamic surveys using the EM61-MK2 and the MetalMapper and cued surveys with the TEMTADS. Arcadis was the PI and performed all data collection, QC, and processing with one exception. Arcadis processed the dynamic MetalMapper data using a peak picking algorithm, while Acorn used the dipole response filter, or Informed Source Selection (ISS) method, to process the data. Geometrics provided additional training in the MetalMapper and NRL provided training to field staff on the TEMTADS (Arcadis, 2015).
3. **Closed Castner Range (CCR) at Fort Bliss, Texas:** Two Arcadis data analysts, Mr. Steve Stacy and Mr. Gabriel Hebert, performed AGC analysis on the cued TEMTADS data that was collected by URS Group, Inc. (URS) (Arcadis, 2017).

Arcadis also analyzed the Pole Mountain and Massachusetts Military Reservation datasets; however, these were training exercises and therefore, no technical reports were written for these sites. These are not described in this report.

Appendix A provides the point of contact information for the Arcadis personnel involved in this contract, the ESTCP Program Office personnel, and the Remedial Project Manager (RPM) for the U.S. Navy, who was involved in the 29 Palms demonstration.

1.2 OBJECTIVES OF THE DEMONSTRATIONS

The Department of Defense (DoD) is responsible for investigating and cleaning up thousands of MRSs comprising millions of acres that are potentially impacted by Munitions and Explosives of Concern (MEC). Current industry-standard practice includes DGM surveys and excavating many subsurface metallic objects that are not MEC. These non-MEC items do not have an explosive hazard, yet their excavation represents most of DoD's MEC cleanup costs. Advanced EMI sensors and advanced software algorithms (*e.g.,* in UX-Analyze Advanced) can successfully classify geophysical targets at MRSs into feature classes that differentiate between TOI (*e.g.,* MEC and Industry Standard Objects [ISOs]) and non-TOI (e.g., non-hazardous munitions debris [MD] and scrap metal). The ability to classify targets will allow project teams to focus intrusive investigation on buried items that pose a potential explosive hazard (*e.g.,* MEC), reduce the costs of remediation, and minimize the impacts to the environment and the public who must evacuate areas during intrusive operations.

The primary objectives of this demonstration were to:

- Compare the effectiveness of traditional DGM sensors vs. advanced EMI sensor in detecting anomalies that are potential TOI.
- Compare the effectiveness of the MetalMapper and TEMTADS in the AGC process.
- Evaluate the cost and performance of dynamic and static data collection methods, as well as the effectiveness of data analysts in correctly classifying TOI.
- Train Military Munitions Response Program (MMRP) contractors in the data collection, QC, and data processing methods involved in the AGC process to facilitate technology transfer from the research community to MMRP production contractors.
- Identify lessons learned and areas for improvement in the AGC process and in training staff.

1.3 REGULATORY DRIVERS

The MMRP is charged with characterizing and, where necessary, remediating MEC at MRSs. The Defense Science Board observed in its 2003 report that significant cost savings could be realized if successful classification between munitions and other sources of anomalies could be implemented (Office of the Under Secretary of Defense for Acquisition [OSDA], 2003). If these savings were realized, the limited resources of the MMRP could be used to accelerate the remediation of MRSs that are currently forecast to be untouched for decades. The ESTCP Live Site Demonstrations were conducted under the DoD MMRP program that is part of the Defense Environmental Restoration Program (DERP).

2.0 TECHNOLOGY

Three geophysical sensors were used at the three Live Site Demonstrations. Brief details of each technology are provided below. **Table 2-1** shows the EMI sensors used at each demonstration site.

Table 2-1. Technologies Used on Live Site Demonstrations

Technology	CEMR	29 Palms	CCR
Dynamic Survey Sensors	EM61-MK2, MetalMapper, and TEMTADS with RTK DGPS	EM61-MK2 and MetalMapper with RTK DGPS	URS conducted TEMTADS surveys in litter mode with RTK DGPS
Dynamic Processing Methods	Peak-picking	Peak-picking: EM61-MK2 and MetalMapper Dipole Response: MetalMapper	Peak-picking
Cued Survey Sensors	MetalMapper with RTK DGPS, TEMTADS in local coordinates	TEMTADS with RTK DGPS	URS conducted TEMTADS surveys in litter mode with RTK DGPS
Cued Analysis Methods	Library Matching and Cluster Analysis		

Note:
RTK – Real Time Kinematic
DGPS – Differential Global Positioning System

2.1 TECHNOLOGY DESCRIPTION

2.1.1 Geonics EM61-MK2

The Geonics EM61-MK2 is the industry standard DGM survey sensor. It consists of a lower, 1.0-meter (m) x 0.5-m transmitter (Tx) /receiver (Rx) coil and an upper, 1.0-m x 0.5-m Rx coil (see **Figure 2-1**). The EM61-MK2 is a time-domain EMI sensor that transmits a current through an electrical loop, which induces a primary magnetic field that magnetizes buried (or surface) objects. Turning off the Tx current causes an abrupt change in the magnetic field, which in turn excites eddy currents within the metallic object. These eddy currents decay as a function of time and are recorded by four Rx time gates.

2.1.2 NRL TEMTADS

The TEMTADS is a man-portable (MP) advanced EMI sensor array (see **Figure 2-2**) based on NRL's larger, 5x5 TEMTADS array. The TEMTADS consists of four 35-centimeter (cm) Tx coils with four 8-cm tri-axial Rx cubes. The TEMTADS was developed through ESTCP (Kingdon, 2012) and has been shown to reliably retain the performance of the original TEMTADS in a much smaller size, which enables the MP version to access difficult terrain where mobility is limited (ESTCP, 2012a and 2012b; Kingdon, 2012). Arcadis operated the TEMTADS system in both dynamic and static mode without making modifications to the system. See the TEMTADS operations manual for more details on the sensor (NRL, 2014).

Figure 2-1. Geonics EM61-MK2 at 29 Palms

Figure 2-2. TEMTADS at 29 Palms

2.1.3 Geometrics MetalMapper

The Geometrics MetalMapper is the first commercially available advanced EMI sensor designed specifically for AGC. It consists of three orthogonal 1-m^2 Tx coils and seven 10- cm, 3-component, orthogonal Rx coils (see **Figure 2-3**). The system was developed in collaboration with ESTCP (Prouty, 2011) and was validated during the ESTCP live demonstration at the former Camp San Luis Obispo (Nelson et. al, 2010; Prouty, 2009) and other live sites to be effective at correctly classifying TOI and non-TOI. Arcadis used the commercially available MetalMapper without making modifications to the system.

Figure 2-3. Geometrics MetalMapper at 29 Palms

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The major advantage of the advanced EMI sensors and UX-Analyze Advanced module is that combined, they provide the ability to classify anomalies as being due to either TOI or non-TOI. This can lead to significant cost savings in MMRP cleanups. Additional advantages and limitations of each technology used during the three live site demonstrations are described in the below sections.

2.2.1 EM61-MK2

The advantages of the EM61-MK2 are that it 1) is widely available and is the industry standard for detection of subsurface MEC, 2) is the most efficient dynamic detection sensor, and 3) can be arranged in arrays and towed by vehicles to increase the amount of area that can be surveyed in a day. The limitations of the EM61-MK2 include: 1) it has little to no ability to classify anomalies in dynamic mode, 2) there is no ability to operate the instrument in cued mode to perform AGC, and 3) the positions of the detected anomalies aren't as accurate as the advanced EMI sensors because it only has a single Rx coil.

2.2.2 TEMTADS

The advantages of the TEMTADS include: 1) it is a MP advanced EMI sensor that can be used in dynamic and cued mode to classify targets as TOI and non-TOI, and 2) the sensor and computer are more ruggedized than the MetalMapper counterparts. The TEMTADS was used in dynamic mode at CEMR and some of the limitations encountered there (*e.g.,* only had two wheels) were subsequently rectified. The limitations of the current configuration of the TEMTADS include: 1) the sensor proved difficult to push in dynamic mode at CEMR due to the short 20-cm sensor height and the short corn stalks that were located along the corn rows, 2) it requires a considerable amount of grid setup time to place ropes across grids to use for straight-line profiling during dynamic surveys, 3) the smaller footprint relative to the MetalMapper requires a smaller line-spacing to ensure 100% coverage and thus it takes more time to collect an equivalent amount of data on a per acre basis, and 4) targets must be reacquired prior to collecting cued TEMTADS data in order to navigate to the target location.

2.2.3 MetalMapper

The advantages of the MetalMapper include: 1) it is an advanced EMI sensor that can be used in dynamic and cued mode to classify targets as TOI and non-TOI, 2) using the skid steer allows the sensor to be placed near the ground at a constant height of 15-cm on relatively flat terrain, 3) there is no need to set up ropes or grids to navigate in dynamic mode, and 4) the sensor operator can navigate to cued target locations using the software without reacquiring targets and placing pin flags. The limitations of the MetalMapper include: 1) it requires a forklift or skid steer or other tow vehicle to transport it; therefore, it is not suitable for work in forested areas, and the tow vehicle can disrupt loose soil (*e.g.,* unconsolidated sand at 29 Palms) and move Instrument Verification Strip (IVS) ISOs or subsurface TOI in production grids, 2) the sensor and the computer have limited durability, and 3) using the MetalMapper in randomly placed grids (*e.g.,* 100-feet [ft] x 100-ft grids randomly placed around a site) significantly reduces the dynamic production rate due to increased amount of time required to turn the sensor around.

3.0 PERFORMANCE OBJECTIVES

Performance objectives or Measurement Quality Objectives (MQOs) were developed and documented in the demonstration plans to measure the quality of the data collected during each ESTCP Live Site demonstration. MQOs were developed for both dynamic and cued data collection and interpretation. **Table 3-1** and **Table 3-2** respectively show the dynamic and cued MQOs and results for each of Arcadis' three Live Site Demonstrations. The CCR data was collected by URS under a separate ESTCP contract and therefore, field-related MQOs for CCR are not included in **Table 3-1** and **Table 3-2** unless they had a direct bearing on the ability to perform AGC. Further discussion of the results is provided in **Section 7.0** of this report.

Table 3-1. Dynamic Performance Metrics and Results for Arcadis' Live Site Demonstrations

Performance Objective	Metric	Data Required	CEMR		29 Palms		CCR	
			Success Criteria	Results	Success Criteria	Results	Success Criteria	Results
Initial Instrument Function Test	Instrument Response Amplitude	Sensor function test (*i.e.*, static test)	NA	NA	Response (mean static spike minus mean static background) within 20% of predicted response for all Tx/Rx combinations	MQO achieved	NA	NA
Spatial Coverage in Detection Survey	Extended footprint coverage	Mapped survey data	98% coverage	EM61-MK2 and MetalMapper achieved MQO. TEMTADS: Did not meet MQO; 95.3% pass	100% at ≤0.5-m cross-track measurement spacing	MQO achieved	NA	NA
Along-line Measurement Spacing	Point-to-point spacing from data set	Mapped survey data	98% of data < 0.15-m	EM61-MK2 and MetalMapper MQO achieved. TEMTADS: Did not meet MQO; 96.5% pass	98% ≤ 0.25-m between successive measurements	MQO achieved	NA	NA
Dynamic Detection Performance	Percent detected of seeded items	Location of Blind Seed Items (BSIs) and anomaly list	100% of seeded items detected within 0.6-m halo	EM61-MK2: 2 BSIs did not meet MQO; MetalMapper met MQO; TEMTADS not evaluated	100% of BSIs detected within 0.4-m halo	MQO achieved	NA	NA
IVS Repeatability	Location and amplitude of anomaly	Twice-daily IVS survey data	Amplitude within 25%; Down-track location ±25-cm	MQO achieved for EM61-MK2 and MetalMapper. TEMTADS not evaluated.	Detection: Amplitude within 25%; Derived Position within 0.5-m	MQO not achieved. Position 94% pass. Amplitude 76% Pass.	NA	NA
Production Rate	Number of acres of data collection per day	Log of field work and data analysis time accurate to 15 minutes	1 acre/day	EM61-MK2 and MetalMapper achieved MQO. TEMTADS did not meet MQO: 0.8 acres/day.	NA	NA	NA	NA
Sensor Tx Current	Per Dataset	Mapped survey data	NA	NA	Peak Tx current between 4.2 and 5 A	MQO achieved	NA	NA
Acceptable Sensor Response	Response Amplitude within valid range	Mapped survey Data	NA	NA	MetalMapper Responses must be approximately between 0 and 10^3 mV/A	MQO achieved	NA	NA
Valid Position Data (1)	GPS status	Mapped survey data	NA	NA	GPS status indicates RTK fix	MQO achieved	NA	NA
Valid Position Data (2)	IMU Status	Mapped survey data	NA	NA	Valid orientation data	MQO achieved	NA	NA

Note:
NA – Not Applicable
A – amp
BSI – Blind Seed Item
GPS – Global Positioning System
IMU – Inertial Measurement Unit
IVS – Instrument Verification Strip
mV - milliVolt

Table 1-2. Cued Performance Metrics and Results for Arcadis' Live Site Demonstrations

Performance Objective	Metric	Data Required	CEMR		MCAGC		CCR	
			Success Criteria	Results	Success Criteria	Results	Success Criteria	Results
Initial Sensor Function Test	Instrument Response Amplitude	Sensor function test (*i.e.*, static test)	NA	NA	Response (mean static spike minus mean static background) within 20% of predicted response for all Tx/Rx combinations	MQO achieved	NA	NA
System Functionality	Polarizabilities	Five measurements over a small ISO80 target: 1 each directly under each of the Rx coils and 1 directly under center of array.	NA	NA	Match metric of ≥ 0.95 for each of the inverted polarizabilities	MQO achieved	NA	NA
Initial IVS Background Measurement	Background Measurement Response	Five background measurements 1 centered at the flag and 1 offset 40-cm in each cardinal direction	NA	NA	Amplitude Response curves were repeatable and indicated there are no metal objects at the background location.	MQO achieved	NA	NA
Initial IVS derived polarizability (β) accuracy	β	Initial IVS test and surveyed seed item location	NA	NA	Library Match metric ≥ 0.95 for each set of inverted polarizabilities	Did not meet MQO. 97.5% pass (39 of 40 measurements)	NA	NA
Derived IVS target position accuracy	Fit location	Initial IVS test and surveyed seed item location	All IVS item fit locations within 0.25-m of ground truth locations	MQO achieved	All IVS item fit locations within 0.25-m of ground truth locations	MQO achieved	NA	NA

Table 3.2. Cued Performance Metrics and Results for Arcadis' Live Site Demonstrations (Continued)

Performance Objective	Metric	Data Required	CEMR		MCAGC		CCR	
			Success Criteria	Results	Success Criteria	Results	Success Criteria	Results
Ongoing IVS Background Measurements	Decay amplitudes	Twice daily IVS background measurements	Cued polarizabilities within ±10%	MQO achieved	Amplitude response curves were repeatable and indicated there were no metal objects at the background location	MQO achieved	NA	NA
Ongoing derived IVS polarizabilities precision	Fit metric	Twice daily IVS tests	NA	NA	Library Match to initial polarizabilities metric ≥ 0.95 for each set of three inverted polarizabilities	MQO achieved	NA	NA
Ongoing derived target position precision (IVS)	Fit location	Twice daily IVS tests	NA	NA	All IVS item fit locations within 0.25-m of the known seed item location	MQO achieved	NA	NA
Cued interrogation of anomalies	Instrument position	Cued survey data	100% of anomalies where the center of the instrument is positioned within 40-cm of the BSI location	Did not meet MQO. One MetalMapper and one TEMTADS target failed	100% of anomalies where the center of the instrument is positioned within 40-cm of the BSI location	MQO achieved	NA	NA
Initial measurement of production area background locations	Background Measurement Response	Five background measurements: 1 centered at the flag and 1 offset 40cm in each cardinal direction)	NA	NA	Repeatable amplitude response curves indicate there were no metal objects at the background location.	MQO achieved	NA	NA

Table 3.2. Cued Performance Metrics and Results for Arcadis' Live Site Demonstrations (Continued)

Performance Objective	Metric	Data Required	CEMR		MCAGC		CCR	
			Success Criteria	Results	Success Criteria	Results	Success Criteria	Results
Ongoing production area background measurements	Background Measurement Response	Background data nominally collected every 2 hours	NA	NA	Repeatable amplitude response curves indicate there were no metal objects at the background location.	MQO achieved	NA	NA
Ongoing instrument function tests	Sensor response	Static sensor function test with every background measurement	NA	NA	Response within 25% of predicted response for all Tx/Rx combinations	MQO achieved	NA	NA
Tx current levels	Sensor response	Cued survey data	NA	NA	Peak Tx current between 5.5 and 9 A.	MQO achieved	NA	NA
Production Rate	Time required to analyze each target	Log of data analysis accurate to 15 minutes	< 5 minutes/target	MQO achieved	NA	NA	NA	NA
Sensor response within valid range	Sensor response	Cued survey data	NA	NA	Values must be within ± 4.2 Volts (V)	MQO achieved	NA	NA
Confirm all background measurements are valid	Sensor response	Background measurements	NA	NA	All decay amplitudes qualitatively agree with initial measurement	MQO achieved	All decay amplitudes lower than project threshold and qualitatively agree with initial measurement	MQO achieved
Confirm all measurements have an applicable background	Background measurements	Cued survey data	NA	NA	Time Separation between background measurement and anomaly measurement < 2 hours	MQO achieved	Time Separation between background measurement and anomaly measurement < 2 hours	MQO not achieved. Analyst 1: 84.3% < 2-hrs and Analyst 2: 80.6% < 2-hrs after removing bad backgrounds

Table 3.2. Cued Performance Metrics and Results for Arcadis' Live Site Demonstrations (Continued)

Performance Objective	Metric	Data Required	CEMR		MCAGC		CCR	
			Success Criteria	Results	Success Criteria	Results	Success Criteria	Results
Confirm GPS precision	GPS Position of control monument	Daily geodetic function tests	NA	NA	Control Monument positions repeatable to within 10-cm	MQO achieved	NA	NA
Valid Position Data (1)	GPS status flag	Cued survey data	NA	NA	GPS status flag indicates RTK fix	MQO achieved	Confirm GPS status flag indicates RTK fix	MQO achieved
Valid Position Data (2)	Orientation data	Cued survey data	NA	NA	Orientation data valid data input string checksum passes	MQO achieved	Orientation data valid data input string checksum passes	MQO achieved
Confirm inversion model supports classification (1 of 3)	Fit Coherence	Cued survey data	NA	NA	Derived model response must fit the observed data with a fit coherence ≥ 0.8	Did not meet MQO. 95.3% (636 of 667 targets) ≥ 0.8	Derived model response must fit the observed data with a fit coherence ≥ 0.8	MQO not achieved. 98% ≥ 0.8 for both analysts
Confirm inversion model supports classification (2 of 3)	Fit location	Cued survey data	NA	NA	Fit location estimate of item ≤ 0.4m from center of sensor	Did not meet MQO. 95.2% (635 of 667) ≤ 0.4-m	Fit location estimate of item ≤ 0.4m from center of sensor	MQO achieved
Confirm inversion model supports classification (3 of 3)	Fit Location	Cued survey data	NA	NA	NA	NA	100% of blind seed item positions ≤ 0.25-m from predicted position (x, y, z)	MQO not achieved. Analyst 1: 71.4% and Analyst 2 75% ≤ 0.25-m
Confirm derived features match ground truth (1 of 2)	Fit Location	Prioritized classification dig list and dig results	NA	NA	100% of recovered (excluding can't analyze category) item positions ≤ 0.25-m from predicted position (x, y)	MQO achieved	100% of recovered (excluding can't analyze category) item positions ≤ 0.25-m from predicted position (x, y)	MQO not achieved. Analyst 1: 80% and Analyst 2 66% ≤ 0.25-m

Table 3.2. Cued Performance Metrics and Results for Arcadis' Live Site Demonstrations (Continued)

Performance Objective	Metric	Data Required	CEMR		MCAGC		CCR	
			Success Criteria	Results	Success Criteria	Results	Success Criteria	Results
Confirm derived features match ground truth (2 of 2)	AGC results	Prioritized AGC dig list and dig results	NA	NA	100% of recovered object size estimates (excluding can't analyze category) qualitatively match predicted size	MQO achieved	100% of recovered object size estimates (excluding can't analyze category) qualitatively match predicted size	MQO not achieved.
Validation of TOI/non-TOI thresholds	AGC results	Prioritized AGC dig list and dig results	100% of predicted non-TOI intrusively investigated are non-TOI	Did not meet MQO. Two MetalMapper and one TEMTADS target incorrectly classified as non-TOI.	100% of predicted non-TOI intrusively investigated are non-TOI	MQO achieved	100% of predicted non-TOI intrusively investigated are non-TOI	MQO not achieved. 83% of TOI correctly classified for both analysts.
Maximize correct classification of non-TOI	Number of false alarms eliminated	Ranked anomaly list and IDA scoring report	Reduction of clutter digs required by ≥ 75% while retaining all TOI.	Did not meet MQO. MetalMapper: 59.2% reduction. TEMTADS: 50-55% reduction.	NA	NA	NA	NA
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as "Cannot Analyze"	Demonstrator target parameters	Reliable target parameters can be estimated for > 95% of anomalies on the detection list.	Did not meet MQO. MetalMapper: 92.98%. TEMTADS: 93.18%	NA	NA	NA	NA
Correct estimation of target parameters	Accuracy of estimated target locations for seed items	Target parameters and results of intrusive investigation	X,Y < 15-cm and Z < 10-cm	Did not meet MQO. MetalMapper: (7) failed horizontal and (3) failed the vertical MQO. TEMTADS: (4) failed horizontal and (3) failed the vertical MQO.	NA	NA	NA	NA

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4.0 SITE DESCRIPTIONS

Table 4-1 presents a summary of the conceptual site model for each of the three sites at which Arcadis performed a live site demonstration. For further details, refer to the respective technical reports.

Table 4-1. Live Site Demonstrations

Site Characteristics	CEMR	29 Palms	CCR
Site Description	Wide variety of training activities during World War II. Area A is approximately 52 acres. Used for rifle grenade, hand grenade, and rocket training.	Munitions Response Program Site Unexploded Ordnance (UXO) 01 is a former Small Arms and Mortar Range and is 79 acres	Wide variety of training from 1920s through 1960s and is approximately 6,800 acres
Surficial Geology	Silty loam and glacial till composed of a mixture of sand, silt, clay, and gravel (CH2MHill, 2009)	Unconsolidated deposits of eolian sands, alluvial sands and gravels and potentially quartz monzonite (Jacobs Engineering Group, Inc., 1995)	Depositional sands and gravels
Current Land Use	Farmland	Other than operational range; no current use	No current use
Potential Munitions Contamination	2.36-inch (in) rockets, Rifle and hand grenades	60-millimeter (mm) mortars: high explosive (HE), white phosphorous (WP), illumination; 81-mm mortars: HE, WP, and illumination; flares; smoke grenades; 40mm grenades; AG-4; and 25-mm projectiles.	Grenades (hand, rifle, smoke); small, medium, and large projectiles (20-mm – 155-mm); mortars; rockets; and small arms.

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5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

This section describes the activities that were conducted by Arcadis in support of the live site demonstrations. **Table 5-1** shows the conceptual experimental design and tasks performed to complete each of the live site demonstrations. Refer to the respective technical reports for further details on the test design for each of the live site demonstrations.

5.2 SITE PREPARATION

Several activities occurred prior to data collection to ensure the resulting data would support successful demonstrations. These activities included a survey of historical records; a civil survey to establish survey control monuments for use as a base station for Real-Time Kinetic (RTK) DGPS and to survey the grid corners, seed items, and Blind Seed Items (BSIs); a surface sweep to remove any MEC or metallic debris from the surface; vegetation removal; construction of an IVS per ESTCP guidelines; and emplacement of BSIs within the area of investigation.

5.3 SYSTEM SPECIFICATION

5.3.1 EM61-MK2

The Geonics EM61-MK2 sensor was used at CEMR and the Marine Corps Air Ground Combat Center (MCGACC) to collect dynamic DGM data within the demonstration sites, as well as for post-dig anomaly resolution to ensure that the source(s) of anomalies were recovered during intrusive investigation. The EM61-MK2 was operated using the standard, factory-programmed four time gates on the bottom coil. Data was collected at a frequency of 10 Hertz (Hz) and positioned using a Trimble RTK DGPS that was updated at a frequency of 1 Hz. Ropes and measuring tapes were used to assist with straight line profiling. The EM61-MK2 was operated in accordance with (IAW) the Geonics operations manual and the approved Demonstration Plan for both sites.

5.3.2 TEMTADS

Arcadis collected dynamic TEMTADS data at CEMR and cued TEMTADS data at CEMR and 29 Palms. Additionally, two Arcadis analysts conducted AGC of the cued TEMTADS data collected by URS at CCR. The TEMTADS was developed by NRL and further details on the sensor specifications can be found in the TEMTADS operations manual (NRL, 2014). Arcadis did not make modifications to the TEMTADS system during the live site demonstrations.

5.3.3 MetalMapper

Arcadis collected dynamic MetalMapper data at CEMR and 29 Palms and cued data at CEMR. The MetalMapper was developed by Geometrics and further details on the sensor specifications can be found in Prouty, 2009. Arcadis did not make modifications to MetalMapper system during the live site demonstrations.

Table 5-1. Project Details for Demonstration Sites

Project Component	CEMR	29 Palms	CCR[1]
Demonstration/ Work Plan	• Demonstration Plan • Site Safety and Health Plan	• Geophysical Classification for Munitions Response-Quality Assurance Project Plan (GCMR-QAPP)	• GCMR-QAPP
Site Preparation	• 5-acre demonstration site • 100 BSIs • Surface sweep and corn stalk removal • IVS construction	• 79-acre demonstration site • 38 100-ft x 100-ft grids (3.44 acres) • 75 BSIs • Surface sweep and vegetation removal • IVS construction	• 5-acre demonstration site • 60 BSIs • Surface sweep and vegetation removal • IVS construction
Calibration Activities	• Twice daily QC static background and static spike testing • Twice daily IVS • Cued background measurements • TOI test pit measurements • Instrument functionality testing	• Twice daily QC static background and static spike testing • Twice daily IVS • Cued background measurements, • TOI test pit measurements • Instrument functionality testing	• Twice daily QC static background and static spike testing • Twice daily IVS • Cued background measurements, • TOI test pit measurements • Instrument functionality testing
EM61-MK2 Data Collection	5 acres of dynamic data (0.75-m line spacing)	38 grids of dynamic data (0.6-m line spacing); conducted as part of concurrent RI	NA
TEMTADS Data Collection	• 0.7 acres of dynamic data (0.4-m line spacing) • 1,086 cued targets	• No dynamic data collected • 667 cued targets	• 5 acres of dynamic data • 1,495 cued targets over 2.5 acres
MetalMapper Data Collection	• 5 acres of dynamic data (0.5-m line spacing) • 0.7 acres of dynamic data (0.4-m line spacing) • 1,196 cued targets	• 3.44 acres of dynamic data (0.5-m line spacing) • No cued data collected	NA
EM61 Data Processing	See **Sections 6.1** and **6.2**	See **Sections 6.1** and **6.2**	NA
TEMTADS Data Processing	See **Sections 6.1** and **6.2**	See **Sections 6.1** and **6.2**	See **Sections 6.1** and **6.2**
MetalMapper Data Processing	See **Sections 6.1** and **6.2**	See **Sections 6.1** and **6.2**	NA
TEMTADS Classification	See **Section 6.2 – 6.5**	See **Section 6.2 – 6.5**	See **Section 6.2 – 6.5**
MetalMapper Classification	See **Section 6.2 – 6.5**	See **Section 6.2 – 6.5**	NA
Intrusive Investigation	• All targets were investigated. • Items recovered were photographed, categorized (name, size, depth, and position), and removed.	• Per the RI, 42 targets were investigated. • Items recovered were photographed, categorized (name, size, depth, and position), and removed.	• 1,525 targets dug

Note: 1 – URS conducted the field component of the CCR Live Site Demonstration. The values reported in this table are from their Final Cost and Performance Report (URS, 2016).

5.4 DATA COLLECTION

5.4.1 EM61-MK2

The EM61-MK2A was used to collect 100% coverage DGM data across five acres at CEMR and 8.72 acres at 29 Palms. The EM61-MK2A was operated in wheel mode with the 1.0-m edge perpendicular to the direction of travel along lines spaced 0.75-m and 0.6-m apart for CEMR and 29 Palms, respectively. The EM61-MK2A data logger collected data from the four time gates on the bottom channel at a rate of 10 Hz, and positional data from the RTK DGPS were collected at a rate of 1 Hz for both sites. The downline data density was less than 0.15-m and less than 0.25-m for more than 98% of the data at CEMR and 29 Palms, respectively. QC checks for the EM61-MK2 data included:

- Initial IVS surveys;
- Twice daily IVS surveys (beginning and end of each day);
- Twice daily static background, spike, and background tests (beginning and end of each day);
- Daily cable shake and personnel tests; and
- Dynamic repeatability offset and response in the production area (i.e., blind seeding).

EM61 data were recorded into binary file formats with a .p61 extension. These formats were converted into the final .xyz format in Geosoft for data processing and analysis.

5.4.2 TEMTADS

The TEMTADS was used to collect dynamic data at CEMR and cued data at both CEMR and 29 Palms. The TEMTADS was also used to collect dynamic and cued data at CCR; refer to the URS report for more details on the data collection parameters at CCR (URS, 2016).

The TEMTADS data was collected in wheeled mode at both sites using the recommended data acquisition parameters in the TEMTADS Operations Manual (NRL, 2014). The amount of data collected is outlined below:

- CEMR:
  - 0.7 acres of dynamic data collected along lines spaced 0.4-m apart
  - 1,086 cued targets were collected
- 29 Palms: 667 cued targets were collected.

For the CEMR dynamic data, data was collected along lines spaced 0.4-m apart and 96.5% of the data had a downline data density ≤ 0.15-m.

The TEMTADS data was collected in .tem format and the GPS data in a .gps file. The data were then converted to Comma-Separated Values (.csv) file and imported into Geosoft Oasis Montaj for data processing and analysis.

5.4.3 MetalMapper

The MetalMapper was used to collect dynamic data at CEMR and 29 Palms and cued data at CEMR. Using the recommended data acquisition parameters in the MetalMapper Operations Manual, MetalMapper data was collected using a sled pushed by a forklift at CEMR and using a skid steer at 29 Palms. The amount of data collected is outlined below:

- CEMR:
  - 5.0 acres of dynamic data collected along lines spaced 0.5-m apart
  - 0.7 acres of dynamic data collected along lines spaced 0.4-m apart
  - 1,196 cued targets
- 29 Palms: 3.8 acres of dynamic data collected along lines spaced 0.5-m apart

For the CEMR dynamic data, the 0.5-m line spacing ensured there was overlap of the transmitter coil between adjacent lines. The dynamic data was also collected along lines spaced 0.4-m apart to match the TEMTADS line spacing to determine the potential effects of varying the line spacing, as well as to allow data comparisons to the TEMTADS data. The downline data density metric was met at both sites: > 98% had less than 0.15-m separation at CEMR and > 98% had less than 0.25-m separation at 29 Palms.

The MetalMapper data were collected in .tem format. The MetalMapper data was converted to a .csv file using the TEM2CSV program and then imported into a Geosoft Database (GDB) for processing.

5.4.4 Advanced EMI Sensor Quality Control

The field data collection team conducted the following QC checks on all days where MetalMapper or TEMTADS data were collected:

- At the beginning of each day, the field team allowed the advanced EMI sensor to warm up for a minimum of 15 minutes.
- Twice daily static background and spike measurements were collected to ensure repeatability of response.
- Twice daily instrument function checks were performed at the IVS to verify the dynamic and/or cued response and positioning repeatability of the complete geophysical system.
- For cued data collection, static background data sets were collected periodically throughout the day at quiet spots to determine the system background level for subtraction.
- Test pit measurements of TOI were made in dynamic and cued modes with the advanced EMI sensors prior to collecting data within the production areas.

5.4.5 Data Validation

After data collection and processing activities, selected targets were investigated per the specifications of the site demonstration: all targets were investigated at CEMR; 42 anomalies were investigated per the RI at 29 Palms; and URS intrusively investigated all anomalies at CCR (URS, 2016). All selected targets were intrusively investigated using the analysis procedures outlined in **Section 6** of this report. These anomalies were reacquired by the geophysical team, dug by the Unexploded Ordinance (UXO) team, and then resolved by the geophysical team.

Arcadis' UXO Technicians met or exceeded the requirements of Technical Paper-18. Each item encountered was identified, photographed, its depth measured, its location determined using cm-level RTK DGPS, and the item removed. Intrusive investigation followed the standard operating procedures included in the approved Demonstration Plan. The intrusive investigation results were documented on field forms and transcribed into an MS Excel spreadsheet that was provided to the ESTCP Program Office. For additional details, see the individual site demonstration reports.

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6.0 DATA ANALYSIS AND PRODUCTS

Two types of data were collected, processed, and analyzed during the live site demonstrations:

- Dynamic data (CEMR and 29 Palms) was pre-processed and, in conjunction with the ESTCP Program Office, target lists were generated from the MetalMapper datasets.
- Static, cued survey data was processed to subtract background measurements, apply a geolocation (CEMR only), and perform AGC of cued MetalMapper and TEMTADS data as follows:
  - MetalMapper: CEMR
  - TEMTADS: CEMR, 29 Palms, and CCR

Once the static data was pre-processed, Arcadis employed physics-based models to extract target parameters and then applied a library matching the AGC algorithm contained in Oasis Montaj's advanced UX-Analyze Advanced module to produce ranked anomaly lists.

6.1 PREPROCESSING

Data was pre-processed using instrument-specific procedures. These pre-processed data were provided for use in target parameter extraction. Below are the instrument-specific pre-processing steps that were employed during this demonstration.

6.1.1 EM61-MK2

Arcadis performed data file QC review and correction of the following in Geosoft Oasis Montaj prior to gridding and target selection of the DGM data:

- Transect or Grid name and location
- Line numbers, survey direction, start and end points
- Drift and latency corrections

6.1.2 TEMTADS

At the time of CEMR data collection, there was no commercially available software to convert the raw, dynamic TEMTADS data in .tem format to a .csv file; therefore, Acorn converted the dynamic files and imported them to an Oasis Montaj GDB. Once in Montaj, channel 4 of the monostatic Z response was multiplied by -1 to make the response positive and then leveled. No latency correction was applied because there was no apparent latency in the dynamic dataset. Once the data were leveled, the leveled channel 4 was gridded for target selection.

The static TEMTADS data was collected in .tem files and the GPS data was collected in .gps files. These files were directly imported into a Geosoft Oasis Montaj GDB using the UX-Analyze Advanced module. Geosoft GDBs were then background corrected prior to further analysis, which is described below. The background response was subtracted from each target measurement using data collected at a nearby target-free background location. The background measurements were reviewed for variability and to identify outliers, which might have corresponded to measurements over metallic items.

6.1.3 MetalMapper

Dynamic and static MetalMapper data was pre-processed by converting the raw .tem file to the .csv file using Snyder Geoscience, Inc.'s TEM2CSV software package. TEM2CSV was also used to convert the GPS-supplied latitude/longitude data to Universal Transverse Mercator (UTM) coordinates, correct the survey location point using attitude data for the MetalMapper platform (heading, pitch, and roll), and remove the background field from all the receiver transients (for static data only). After pre-processing data in TEM2CSV, the CSV file was then imported into Geosoft Oasis Montaj processing environment for further analysis.

6.2 TARGET SELECTION FOR DETECTION

Four dynamic data target lists were generated during the various live site demonstrations. Targets were selected for each target list based on the response for the anticipated TOI for each site. **Table 6-1** provides the dynamic target selection thresholds and rationale for each of the three Arcadis Live Site Demonstrations. Further details are provided in the below sections.

The following sections describe the data processing and target selection methods for each of the dynamic target lists. A final cued target list was developed for each site using one or a combination of the dynamic methods discussed below, and cued data was collected at all the demonstration sites (see **Section 7** for performance assessments).

Table 6-1. Anomaly Selection Thresholds and Rationale for Live Site Demonstrations

Sensor	CEMR		29 Palms		CCR	
	Anomaly Selection Rationale	Threshold	Anomaly Selection Rationale	Threshold	Anomaly Selection Rationale	Threshold
EM61-MK2	Detect 2.36-in rockets at 18-in below ground surface (bgs)	3 mV	Detect 60mm to 21.25-in bgs and 81mm mortars to 22.8-in bgs	7 mV on channel 2	NA	NA
TEMTADS		1 mV on channel 8		NA	See URS, 2016	
MetalMapper		1.9 mV on sum channel[1]		MMPP: 3 mV on sum channel[1] MMDR (or ISS): 0.3 fit coherence peak threshold	NA	NA

Note:
1 - Average of the sum of channels 6-11 of the monostatic Z-component over inner 5 Rx cubes

6.2.1 EM61-MK2

Arcadis processed the EM61-MK2 data at CEMR and 29 Palms. Data was leveled, corrected for latency errors, and then channel 2 was gridded. Targets were selected from the gridded data for anomalies that had a channel 2 response greater than an established target threshold for the expected site TOI at their maximum expected depth and their least favorable orientation. **Figure 6-1** presents an example of the dynamic EM61-MK2 data from 29 Palms. **Table 6-1** lists the anomaly selection criteria used at CEMR and 29 Palms.

6.2.2 TEMTADS

Arcadis processed the dynamic TEMTADS data at CEMR and used a peak picking (PP) anomaly selection method like that used for the EM61-MK2 data. After pre-processing, dynamic TEMTADS data were imported into Geosoft Oasis Montaj. The target selection threshold for the dynamic TEMTADS data was based on a comparison of the measured response of the advanced EMI sensor to the EM61-MK2 response for the TOI listed above at the TOI-specific target depths and targets were selected on channel 8. **Figure 6-2** presents an example of the dynamic TEMTADS data from CEMR and **Table 6-1** lists the anomaly selection criteria at CEMR.

6.2.3 MetalMapper Peak Picking (MMPP)

Dynamic MetalMapper data was collected at CEMR and 29 Palms, and a PP method similar to that used for the EM61-MK2 data was used. After pre-processing, dynamic MetalMapper data were imported into Geosoft Oasis Montaj, and a sum of time gates (6-11 at CEMR and 2-9 at 29 Palms) was created for each of the 5 inner Z Rx cubes (Rx 2 through 6). The Z2 through Z6 sum channels were then leveled using a median filter, ignoring 0% of the lowest values and 50% of the highest values, and using a window length of 100 seconds. The levelled sum channels were then averaged. The average channel was then corrected for minor latency errors based on IVS results and grid corner survey locations and the corrected data was then gridded using a kriging algorithm and targets were selected. An example of the dynamic MMPP data is presented as **Figure 6-3** and **Table 6-1** lists the anomaly selection criteria used at CEMR and 29 Palms.

6.2.4 MetalMapper Dipole Response (MMDR)

Acorn performed the MMDR, or ISS, data processing and target selection as a subcontractor to Arcadis during the demonstration at 29 Palms. **Figure 6-4** shows an example of the MMDR data. The MMDR target selection method takes advantage of all the measured data – not just the Z component – by employing an automated dipole inversion routine to estimate the source locations. The process involves the following procedures:

1. At every 0.1-m grid node, the surrounding data (from a 1.6-m x 1.8-m box) were submitted to a dipole analysis inversion routine to determine the best match for a dipole located at that grid node. The match between the measured data and the derived dipole model (*i.e.* the fit coherence) was used to indicate the presence or absence of a discrete metal source at that location with a high match to a dipole indicating the presence of a metal source.
2. This fit coherence is mapped in the same manner as the amplitude response and peaks in this mapped detection metric indicate target locations. The peaks were initially selected using a custom peak detection routine in Interactive Data Language (IDL) and compared to the Blakely peak detection routine embedded in Geosoft Oasis Montaj. A detection threshold of 0.3 was used for both peak detection methods. All detected peaks regardless of detection method were passed on to the next step.

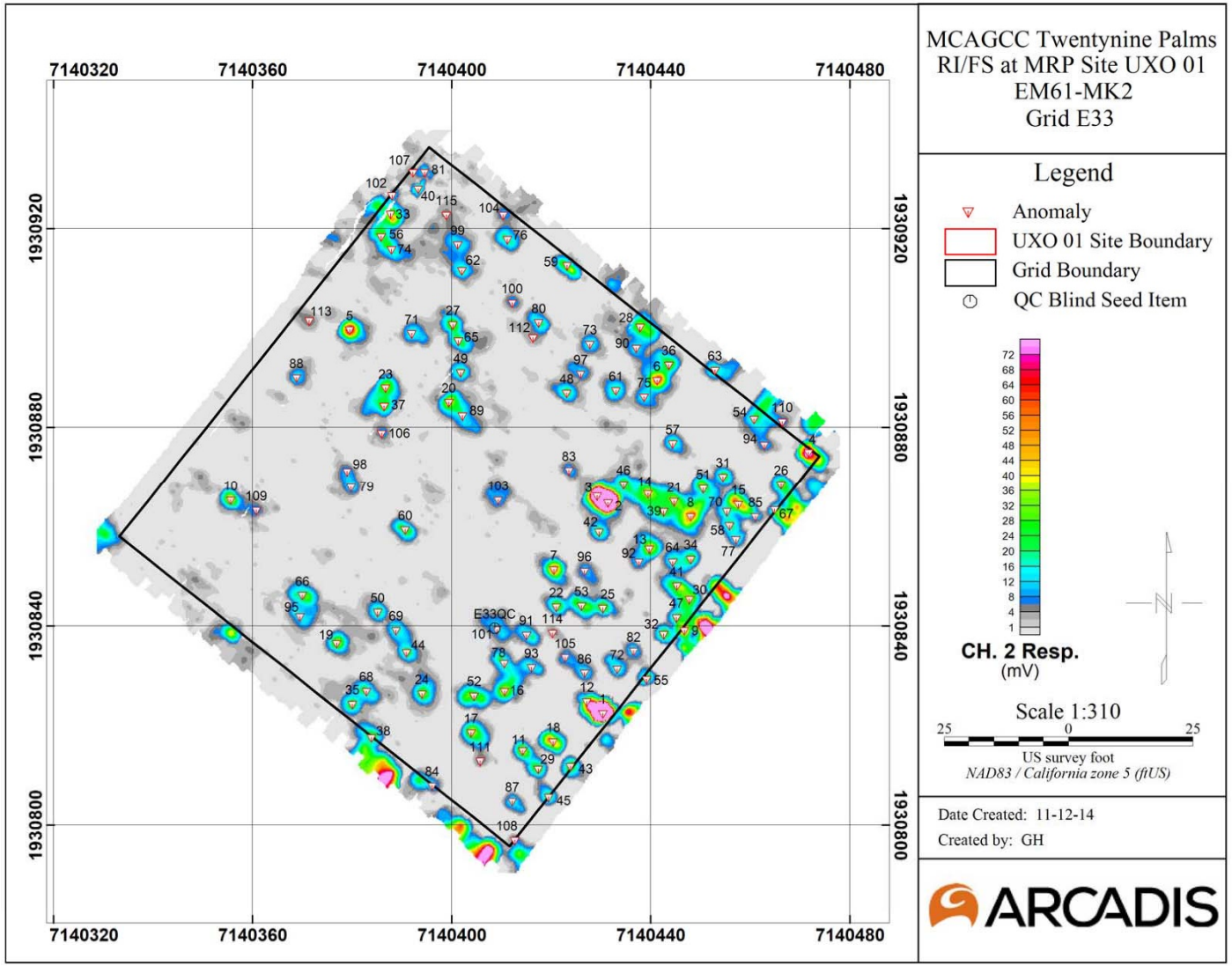

Figure 6-1. 29 Palms Dynamic EM61-MK2 Data

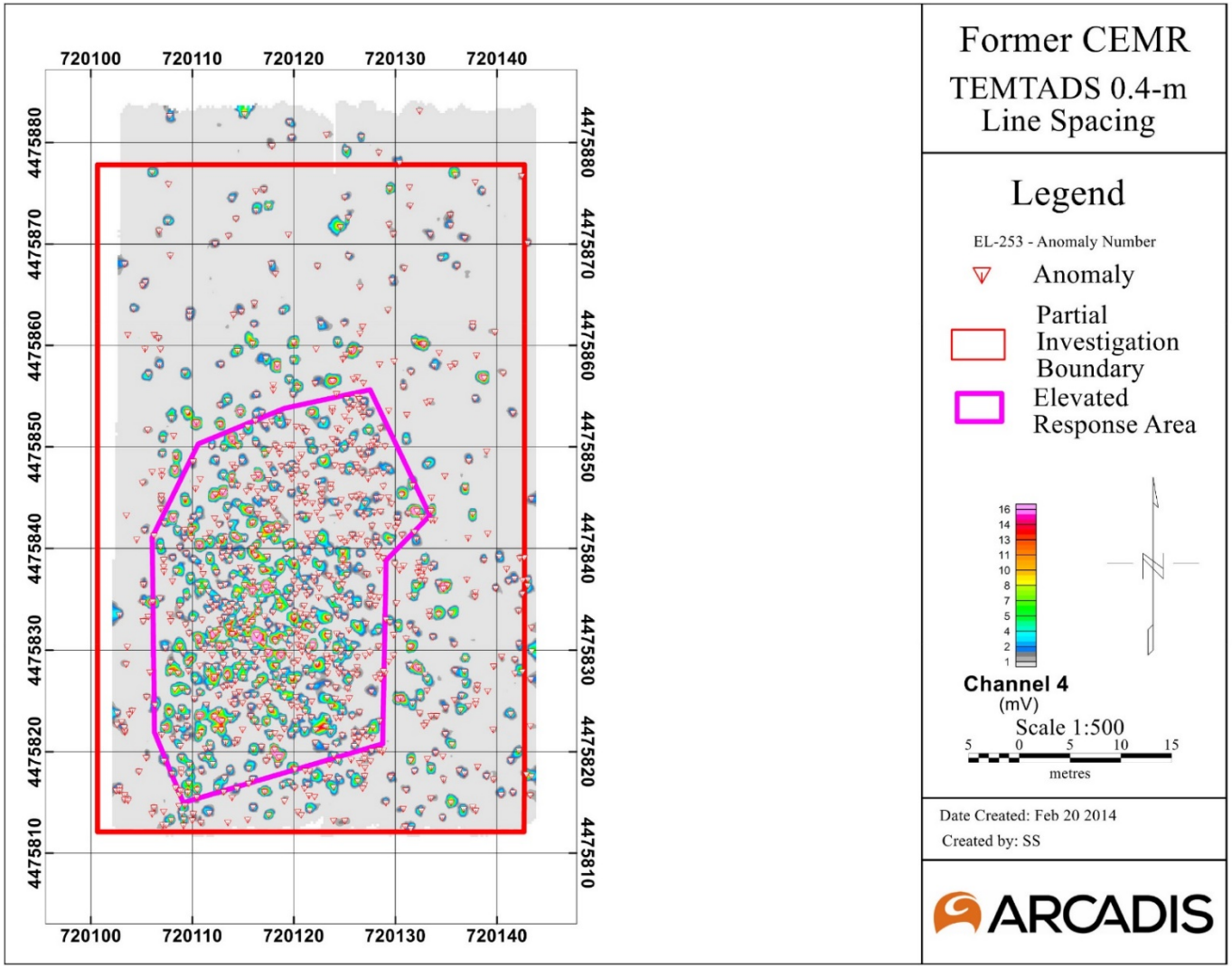

Figure 6-2. CEMR Partial Dynamic TEMTADS Data within Target Area

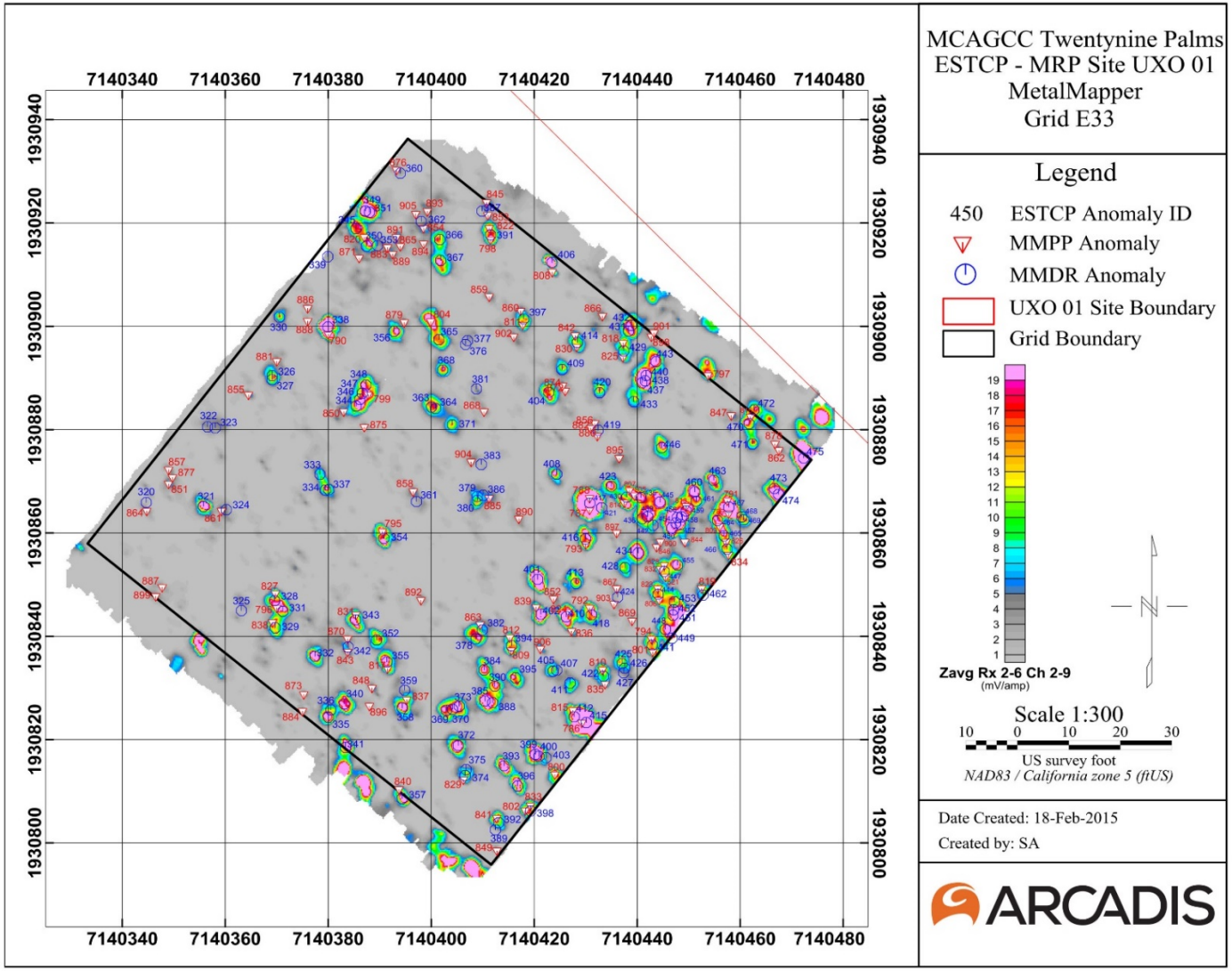

Figure 6-3. 29 Palms Dynamic MMPP Data Example

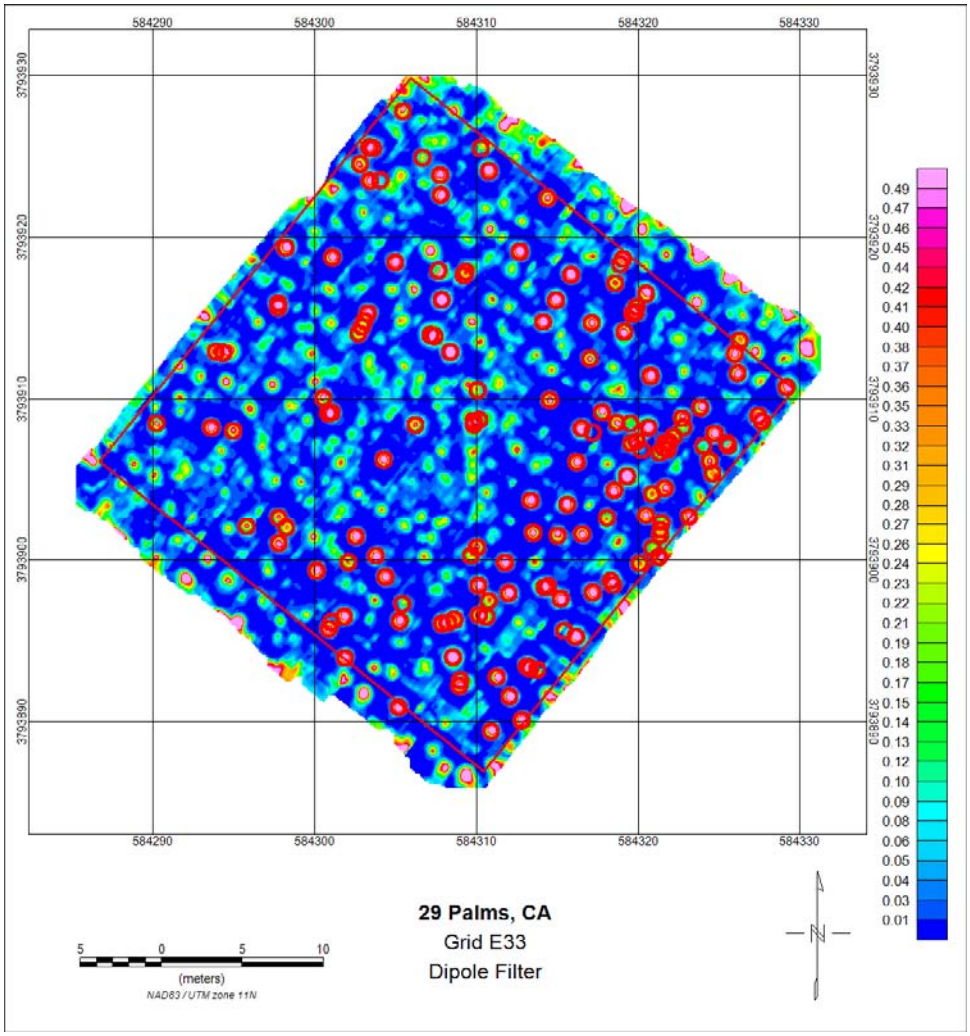

Figure 6-4. 29 Palms Dynamic MMDR Data Example

3. A subset of data around each peak was then subjected to a more computationally expensive process whereby the data were inverted in separate passes for one, two, or three dipole sources, enabling spatial resolution for multiple sources within the footprint of the original dipole response region.
4. Resulting sources were examined and culled (based upon size/decay/amplitude metrics) to only sources that could be a 37mm projectile or larger. The size metric was calculated using polarizations from the 0.137-millisecond (ms) data and the decay metric was calculated by comparing the polarizations from the 0.137-ms data to the 1.022-ms data. The size and decay calculations were done using the routines in UX-Analyze. Any sources with a size less than -1 or decay less than 0.01 were removed from the final source list. Additionally, any source with a size less than -0.5 and decay less than 0.05 were also removed.
5. Fit Easting (X) and Northing (Y) locations from the inversions were used as the source positions.

6. If the location of the source was greater than 0.4-m from the original fit coherence peak an additional inversion was run using data centered on the fit position of the source. The results of additional inversion were also evaluated using the same size/decay/amplitude metrics described previously.
7. All the inversion results were then merged for all the sources into one GDB and a target list was compiled based on the fit position of the sources. All sources that were within 0.2-m of one another were merged into one source and the final source list was generated.

The fit coherence peak threshold of 0.3 used in step 2 was derived by exercising the target selection algorithm on data that is comprised of modeled small ISO signatures superimposed on site specific noise measurements. **Figure 6-5** presents a comparison of the amplitude response signal relative to the noise (left panel) and the dipole filter metric signal relative to noise.

6.3 PARAMETER ESTIMATES

Arcadis analyzed cued MetalMapper data at CEMR and TEMTADS data collected at the three sites to perform AGC. Each selected anomaly was analyzed using the single and multi-object solver algorithm in the UX-Analyze Advanced module within Geosoft Oasis Montaj. Both intrinsic (size, shape, materials properties) and extrinsic (location, depth, orientation) parameters were estimated in these analyses and a list of the relevant target parameters from each analysis compiled. The static data was processed using UX-Analyze Advanced module to extract the three-principal axis polarizability, or β, curves for each target. Arcadis then matched the β curves for each target to a library of β curves to classify the target as either TOI or non-TOI.

6.4 CLASSIFIER

Arcadis' classifier on all three site demonstrations involved matching the measured polarizabilities to a library that contained TOI from previous sites and the site-specific TOI (see **Section 4.0**). The size and shape of polarizabilities (or βs) were matched to the known library items for the following four scenarios:

- **3 component target classification**
  - Size – β_1
  - Shape 1 – β_2/ β_1
  - Shape 1 – β_3/ β_1
- **2 component target classification (1)**
  - Size – β_1
  - Shape 1 – β_2/ β_1
- **2 component target classification (2)**
  - Size – β_1
  - Shape 1 – β_3/ β_1
- **1 component target classification**
  - Size – β_1

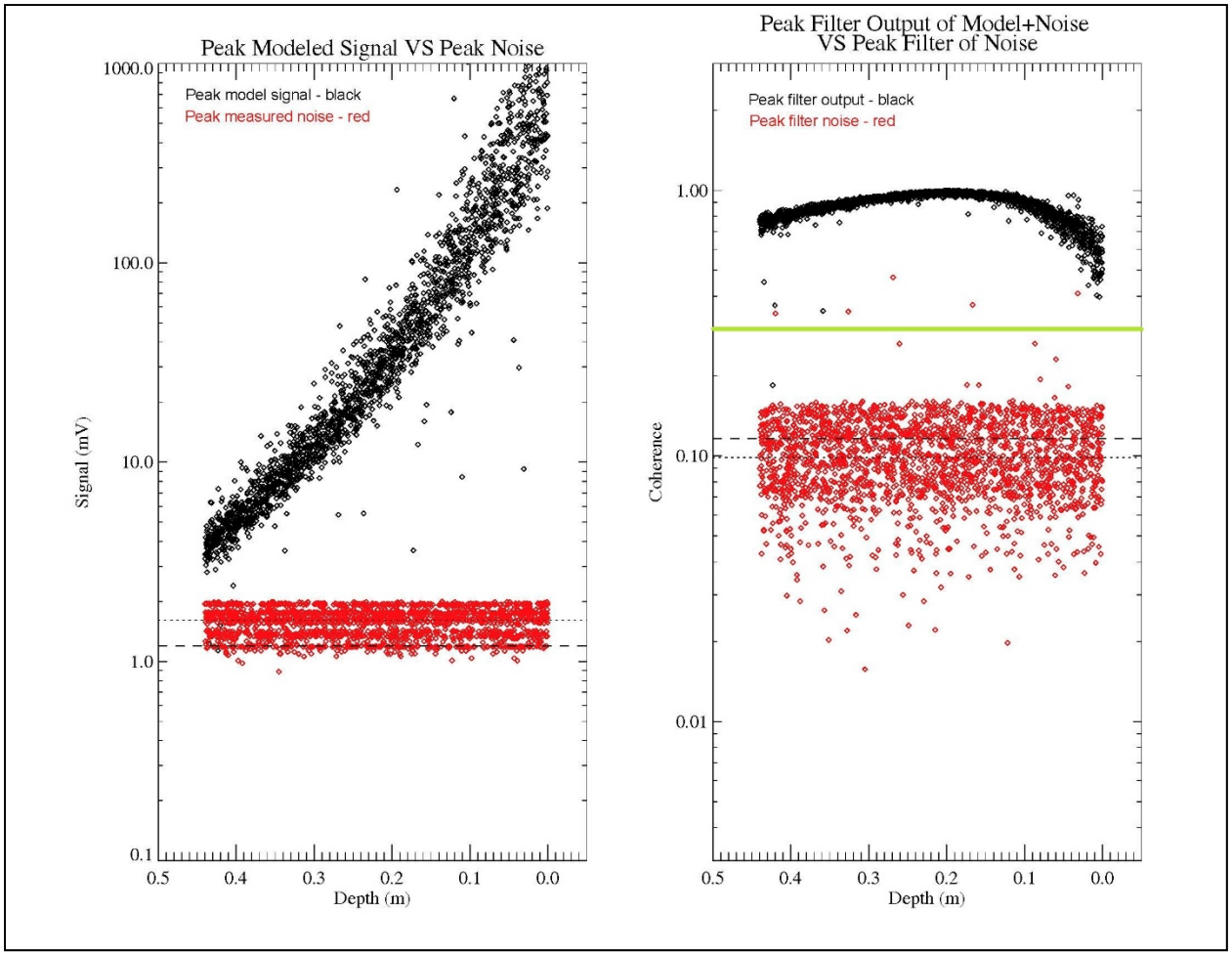

Figure 6-5. MMDR Target Selection at 29 Palms

Arcadis then used the library matches and size/decay feature space plots to identify clusters of anomalies that could have been potential TOI, and to verify that clusters suspected to be non-TOI were in fact due to non-TOI. After the clusters were investigated (*i.e.,* training data was requested), Arcadis produced ranked anomaly lists. The library matching approach for both sensors included matching to TOI, as well as to MD clutter items added to the library at CEMR. The final classification used a combined confidence metric that averaged the confidence metric for the best fitting TOI (or clutter item in the library) for the 3-, 2-, and 1- component matches. The best fitting TOI (or clutter item) for the 3-component match was then assigned as the TOI Type. Arcadis then classified each anomaly as one of the following categories described below:

- *Category 1:* anomalies for which training labels had been requested. These anomalies were placed at the top of the dig list.
- *Category 0:* Anomalies for which Arcadis was not able to extract reliable parameters.
- *Category 1:* Anomalies believed to have a high likelihood of being TOI.
- *Category 2:* Anomalies Arcadis was unsure whether these anomalies were TOI or non-TOI.

- *Category 3:* Anomalies that had a high likelihood of being clutter items and/or a low likelihood of being TOI. These anomalies were placed below the dig threshold.

6.5 DATA PRODUCTS

Arcadis submitted cued anomaly lists for the demonstrations at CEMR and CCR. Not all detected targets were dug at 29 Palms because the contract with the U.S. Navy limited the number of intrusive investigations to approximately 40 targets; therefore, a final ranked anomaly list was not developed for this site. The final ranked dig lists for CEMR and CCR were submitted to ESTCP and IDA scored the results and constructed Receiver Operating Characteristic (ROC) curves for each anomaly list. The ROC curves are presented in the respective technical reports for each site. **Table 6-2** presents a summary of the results of the final ranked anomaly lists for CEMR and CCR. Arcadis' evaluated performances based on correctly classifying QC and Quality Assurance (QA) BSIs are further discussed in **Section 7**.

Table 6-2. Ranked Anomaly List Details

Site	Analyst - Dataset	TOI Identified		Training Targets		Cannot Analyze		List Length		Totals	
		Quantity	%	Quantity	%	Quantity	%	Quantity	%	Total TOI	Total Targets
CEMR	Analyst 1 - MetalMapper	61	98.4%	42	4.2%	71	7.1%	410	40.9%	62	1003
	Analyst 1 - TEMTADS	37	97.4%	55	5.5%	69	6.9%	493	49.2%	38	1012
CCR	Analyst 1 - TEMTADS	34	82.9%	81	5.4%	105	7.0%	651	43.7%	41	1491
	Analyst 2 - TEMTADS	34	82.9%	42	2.8%	100	6.7%	629	42.2%		

7.0 PERFORMANCE ASSESSMENT

Performance objectives were established in each site demonstration plan to evaluate the quality of data collected as part of each demonstration. **Table 3-1** and **Table 3-2** present the MQOs and results for dynamic and cued data, respectively for each site. This section documents the results and evaluates the data quality and whether the MQOs were met. Each of the three demonstrations had different objectives; therefore, not all MQOs applied to each of the sites and some of the MQOs performance metrics differed between the sites. The number of MQOs also greatly expanded between the time of the CEMR and the 29 Palms demonstrations; therefore, many of the MQOs were not applicable at the time of the CEMR demonstration. In addition, URS collected the field data at CCR; therefore, they were evaluated as part of their contract and aren't included in this report except where the MQO directly impacted the AGC performance of Arcadis' analysts.

7.1 DYNAMIC DATA

7.1.1 Initial Instrument Function Test

Arcadis applied this MQO on the 29 Palms demonstration. After assembling the MetalMapper, Arcadis collected a background measurement and a static test measurement using a small ISO80 to ensure that the sensor was properly functioning. Both files were imported into Geosoft Oasis Montaj, the static measurement was background corrected, and anticipated response was compared to the small ISO80 in the target library. The initial instrument function test MQO was achieved.

7.1.2 Spatial Coverage in Detection Survey

Arcadis conducted dynamic detection surveys at CEMR and 29 Palms. Four dynamic detection surveys were conducted at CEMR: EM61-MK2 and MetalMapper surveys across the entire 5-acre site, and MetalMapper and TEMTADS surveys across the 0.7-acre partial investigation area centered on the target area. At 29 Palms, the MetalMapper was used for the dynamic detection survey. The success criteria for the Spatial Coverage metric at CEMR and 29 Palms was that 98% and 100% coverage across the nominal line spacing was achieved across accessible areas, respectively. The percent coverage was calculated for each of the datasets using the calculate footprint coverage algorithm in Geosoft Oasis Montaj's UX-Detect module. **Table 3-1** shows the results for each of the datasets.

All data from CEMR met this metric, except the partial TEMTADS survey, where a single line of data was missed. During data collection with the TEMTADS, the polyvinyl chloride (PVC) handle broke from the platform and had to be repaired. It took several days to procure the appropriate parts and make the handle repairs; the project team determined that completing the data collection on the western side of the site and filling in the missing line was not required to perform the comparison with the other dynamic datasets. At 29 Palms, the average coverage for all the grids surveyed with the MetalMapper was 99.87%; therefore, this MQO was achieved.

7.1.3 Along-line Measurement Spacing

The reliability of the survey data depended on the density of coverage of the site. This MQO concerns the ability of the instrument operator to collect data with acceptable along-line measurement spacing. The along line measurement spacing was calculated using Geosoft Oasis Montaj to determine if greater than 98% of the data had an along line measurement spacing less than 15-cm at CEMR and less than 25-cm at 29 Palms. All the CEMR datasets met the MQO except for the TEMTADS dataset. 3.5% of the TEMTADS dataset exceeded the along line measurement spacing; however, over 99.8% of the dataset had a data spacing less than 20-cm. It should also be noted that along line data spacing requirements are typically on the order of 25-cm. All MetalMapper datasets at 29 Palms had greater than 98% coverage and this MQO was met.

7.1.4 Dynamic Detection Performance

The ESTCP Program Office evaluated the performance of the dynamic detection of all QC and QA BSIs to ensure BSIs were detected in the dynamic surveys. The performance standard for this MQO was that BSIs were found within 0.6-m of their true position at CEMR and within 0.4-m of their position at 29 Palms. All BSIs were found within 0.6-m offset in the CEMR MetalMapper datasets and within 0.4-m offset in the 29 Palms MetalMapper MMDR datasets; therefore, this MQO was achieved at both sites.

7.1.5 IVS Repeatability

IVS measurements were collected twice a day (one in the morning and one at night) to confirm proper instrument functionality and sensor system performance. The metrics for this MQO were the amplitude and down-track position of the peak response for the advanced EMI systems in survey mode. The MQO was achieved if the measured amplitudes for each object were within 25% of the mean and the down-track position of the anomaly peak was within 25-cm of the known location. All CEMR IVS data passed these metrics.

At 29 Palms, dynamic MetalMapper data was collected over ten IVS seed items 25 times for a total of 250 IVS measurements. The positioning offset met the 0.25-m metric 234 out of the 250 times (94%). All failing offsets were from datasets where only a single line of data was collected down the centerline and where the MetalMapper didn't traverse the IVS seed item in the middle of the sensor. These failures were largely seen in the datasets collected on October 29th and 30th, 2014. After these failures were identified, the field team switched to collecting three lines of IVS data: the centerline and a single line on either side of the centerline at the planned line spacing. After switching to collecting data on three lines, all dynamic detection positions met the 0.25-m performance metric. 191 of the 250 measurements (76%) passed the ± 25% response amplitude. There were at least two sources of variation in dynamic response that were identified during the dynamic IVS surveys:

1. Only collecting data on the center line, IAW Geophysical Systems Verification (GSV) guidance (ESTCP, 2009), often led to not collecting data directly over the IVS seed item. The variation in response due to this offset is not known because there weren't response curves available to determine the variation in response to ISOs as a function of offset.

2. A marked increase in IVS seed item response was exhibited for all IVS seed items starting on November 17, 2014. The increased response was likely associated with the MetalMapper sled digging down into the loose sand at the site during the IVS survey in the morning or afternoon. Despite placing wooden boards across each of the IVS seed items to prevent scouring with the MetalMapper; some scouring of the loose sand appears to have occurred that resulted in an effective decrease in the distance between the MetalMapper and IVS seed items and corresponding increases in response.

7.1.6 Production Rate

At CEMR, this MQO was met if the dynamic production rate exceeded 1-acre per day. The dynamic production rates exceeded 1-acre/day for the full coverage datasets; however, the dynamic production rates for the partial MetalMapper and TEMTADS surveys conducted along lines spaced 0.4-m apart were less than 1-acre/day and did not achieve this MQO. The partial datasets had a smaller line spacing (*i.e.*, 0.4-m vs. 0.5-m) and, therefore, took a longer time to collect. The metric established in the demonstration plan was designed for the larger line spacing for the MetalMapper and EM61-MK2 data. Dynamic TEMTADS data collection and the MetalMapper data on lines spaced 0.4-m apart were added to the demonstration once in the field and weren't included in the demonstration plan; therefore, this MQO is considered met.

7.1.7 Sensor Tx Current

At 29 Palms, the performance metric for this MQO was that the sensor's Tx was transmitting current within the expected range. This value was evaluated for each of the datasets and each dataset achieved the MQO.

7.1.8 Acceptable Sensor Response

At 29 Palms, the performance metric for this MQO was that the sensor's Rx responses were within acceptable ranges. The response was evaluated for each of the datasets and each dataset met the MQO.

7.1.9 Valid Position Data (1) – GPS Status

At 29 Palms, the GPS quality metric was used to evaluate whether the GPS was functioning properly during data collection. All data points had a GPS quality of 4, indicating that the data had an RTK fix; therefore, all data achieved this MQO.

7.1.10 Valid Position Data (2) – IMU Status

At 29 Palms, the IMU metric was evaluated to determine whether the IMU was collecting valid heading, pitch, and roll data. All data points had valid IMU data; therefore, this MQO was achieved.

7.2 CUED DATA

7.2.1 Initial Sensor Function Test

After assembling the TEMTADS at 29 Palms, Arcadis collected a background measurement and a sensor function test using a small ISO80 to ensure that the sensor was properly functioning. The sensor function test was compared to the expected response that was contained within the TEMTADS data logger and the initial sensor function test met this MQO.

7.2.2 System Functionality

At 29 Palms, a systems functionality test was conducted to determine whether each Tx and Rx was functioning properly. Arcadis collected the system functionality test in two orientations, one with the BSI north-south and one east-west, for each of five locations: directly under the center of each of the four Rx coils and directly under the center of the TEMTADS. The lowest 3-component match of these tests was a 0.98 match to a small ISO80; therefore, all tests achieved this MQO.

7.2.3 Initial IVS Background Measurement

The reliability of the IVS data at 29 Palms required background measurements that were free of metallic objects that could adversely affect background corrections. Initial measurements were taken at the IVS background location and locations offset by approximately 40-cm in each of the cardinal directions. All initial IVS background locations achieved this MQO because the amplitude response curves were repeatable and indicated there were no metallic objects at the background location.

7.2.4 Initial IVS Derived Polarizability Accuracy

At 29 Palms, four sets of initial IVS data were collected over all 10 IVS seed items; one for each of the onsite crew that would potentially collect cued TEMTADS data. After the initial IVS datasets were collected, the derived polarizabilities were compared to the target library to determine whether the polarizabilities allowed the IVS seed items to be accurately classified. The MQO was met if the Library Match metric was greater than or equal to 0.95 for each IVS seed item. 97.5% (39 of 40) of the measurements met the performance metric. One single measurement taken over seed item 2 failed to meet the 0.95 library match metric. The source appeared to be associated with a lower response over the seed item for this one measurement. This failure was neither repeated by the other 3 cued measurements over the seed item on the initial IVS measurements nor on any ongoing IVS measurements taken at any seed items; therefore, it was not indicative of the TEMTADS not functioning properly and this performance metric was achieved.

7.2.5 Derived IVS Target Position Accuracy

The reliability of the 29 Palms data depended on the ability to accurately determine the location of TOI. The IVS target positions for the four initial IVS tests all passed since the fit locations were within 0.25-m of the surveyed IVS seed item locations; therefore, this MQO was achieved.

7.2.6 Ongoing IVS Background Measurements

The reliability of the 29 Palms IVS data required background measurements that were free of metallic objects. Ongoing measurements were taken at the IVS background location. All IVS background measurements were determined to pass because the amplitude response curves were repeatable and indicated there were no metal objects at the background location; therefore, this MQO was achieved.

7.2.7 Ongoing Derived IVS Polarizabilities Precision

At 29 Palms, ongoing twice daily measurements were made at the IVS with the TEMTADS to verify the proper functioning of the equipment and the ability to correctly classify targets on a consistent basis. After the IVS datasets were collected, the derived polarizabilities were compared to the target library to determine if the decision statistic was greater than or equal to 0.95 for each IVS seed item. All derived polarizabilities and the decision statistic for the matches for the ongoing IVS seed item tests were greater than 0.95 and therefore this MQO was achieved.

7.2.8 Ongoing Derived Target Position Precision (IVS)

At 29 Palms, ongoing twice daily measurements were made at the IVS with the TEMTADS to verify the proper functioning of the equipment and the ability to accurately determine the location of IVS seed items. The target positions for all ongoing IVS seed items met this MQO since the fit locations were within 0.25-m of the surveyed IVS seed item locations.

7.2.9 Cued Interrogation of Anomalies

The reliability of cued data depended on acceptable instrument positioning during data collection in relation to the actual anomaly location. The MQO was met if the center of the instrument was positioned within 40-cm of the actual anomaly location for 100% of the BSIs at CEMR and 29 Palms. The MQO was evaluated by measuring the distance of the seed item center location vs. the location of the center of the cued sensor used to collect data over the seed items. At CEMR, the center of the cued sensors was within the 0.4-m metric for all BSIs except one for each of the sensors. The center of the MetalMapper was 0.51-m away from the center of the seed item at target EL-406, while the center of the TEMTADS was 0.49-m away from the center of the seed item at target EL-143. At 29 Palms, all offsets between the BSIs and the center of the TEMTADS were less than the 40-cm performance metric; therefore, the MQO was met.

7.2.10 Initial Measurement of Production Area Background Locations

At 29 Palms, the reliability of the production data required background measurements that were free of metallic objects that could adversely affect background corrections. Initial measurements were taken at five locations at each background location: one centered at the proposed background location and one offset approximately 40-cm in each cardinal direction. The MQO was met if amplitude response curves were repeatable and indicated there were no metal objects at the background location. Measurements at the northern cardinal direction location at two of the proposed 8 background locations indicated that metallic objects were present. These two background locations were not used to collect background locations once they were identified as not being suitable background locations on the following day.

7.2.11 Ongoing Production Area Background Measurements

At 29 Palms, the reliability of the production data required that valid background measurements were collected less than every 2 hours. A valid background measurement was taken within 2-hour intervals; therefore, this MQO was achieved.

7.2.12 Ongoing Instrument Function Tests

At 29 Palms, the reliability of the cued data required the TEMTADS, GPS, and IMU equipment to be functioning properly throughout the day. This test provided an in-field function test for the field team to determine whether there were instrument issues during data collection. Static sensor function tests were collected whenever a background measurement was collected. The results of the sensor function tests were field verified. The MQO was met if the response was within 25% of predicted response for all Tx/Rx combinations. All sensor function tests passed this MQO.

7.2.13 Tx Current Levels

At 29 Palms, the instrument's detection depth capability and the ability to perform AGC were dependent on the instrument Tx functioning as intended. This metric was evaluated for each of the cued TEMTADS data points and data passed if the peak Tx current was between 5.5 and 9 A. All data met this MQO.

7.2.14 Production Rate

At CEMR, this MQO was met if the cued anomaly analysis production rate was less than 5 minutes per target on average. The cued data analysis time was calculated based on the amount of time spent to QC and analyze the static data. Both the MetalMapper and TEMTADS data took approximately 3.8 minutes per target, which is below the 5 minutes per target metric and therefore, both met this MQO.

7.2.15 Sensor Response within Valid Range

At 29 Palms, the reliability of AGC results depended on the instrument functioning properly and the instrument response being within the expected range. The MQO was met if the response values were within plus or minus 4.2V. All recorded responses achieved this MQO.

7.2.16 Confirm all Background Measurements are Valid

At 29 Palms and CCR, the reliability of the production data required valid, repeatable background measurements that were free of metallic objects that could adversely affect background corrections. The MQO was met if amplitude response curves were repeatable and indicated there were no metal objects at the background location. At 29 Palms, all background measurements except those collected at the A33 and E31 background locations achieved this MQO. Data that required the use of the background data at these two locations were re-collected using a valid background; therefore, this MQO was met. At CCR, Arcadis Analysts 1 and 2 respectively determined that 69 and 64 of the 160 total background measurements were acceptable to use to level cued data. The Arcadis analysts rejected background measurements where metallic objects were apparent in the background data and where the background response was not repeatable. This MQO was not achieved at CCR.

7.2.17 Confirm all Measurements have an Applicable Background

The reliability of cued production data required that valid background measurements were collected to record time-variable effects in background response to minimize their impact to the AGC results. The MQO was considered met at 29 Palms because the time separation between valid background and target measurements was less than 2 hours for all targets. At CCR, Arcadis Analysts 1 and 2 respectively determined that only 69 and 64 of the 160 total background measurements that URS collected were suitable for use in performing background corrections of the cued data. This resulted in the Arcadis analysts having to use background measurements that were taken up to 6 hours away from cued measurements; therefore, the MQO was not achieved for either analyst.

7.2.18 Confirm GPS Precision

At 29 Palms, the reliability of the GPS positions required daily geodetic functionality tests where GPS measurements were collected over a known, control monument location to document proper functioning of the GPS. The MQO was considered met if the control monument positions were repeatable to within 10-cm. All geodetic functionality tests passed and the maximum offset was 0.48-cm; therefore, the MQO was achieved.

7.2.19 Valid Position Data (1) – GPS Status Flag

At 29 Palms and CCR, the GPS quality metric was used to evaluate whether all cued measurements had valid positional data. The RTK fix quality flag was used to evaluate whether each cued measurement had a valid RTK GPS location recorded with it. All cued data had an RTK fix quality of 4, indicating that valid positioning was recorded for each measurement. All data achieved this MQO.

7.2.20 Valid Position Data (2) – IMU

At 29 Palms and CCR, the IMU data was evaluated to ensure that all cued data had valid roll, pitch and yaw values. The IMU data stream recorded in each cued measurement were evaluated by checking the raw data import for a valid value in each of the UXA_pitch, UXA_yaw, and UXA_roll GDB channels. This MQO was achieved for both sites, as valid pitch, roll, and yaw data streams were recorded for each cued measurement.

7.2.21 Confirm Inversion Model Supports Classification (1 of 3) – Fit Coherence

At 29 Palms and CCR, the reliability of the AGC results depended on collecting data that had a relatively high fit coherence to indicate the data could be modeled. Successful completion required that the derived model response fit the observed data with a fit coherence of greater than or equal to 0.8. At 29 Palms, a total of 636 of the 667 targets (or 95.3%) had a fit coherence greater than 0.8 and passed this MQO. At CCR, 98% of the cued data had inversion results with fit coherences greater than 0.8 for both analysts and achieved the MQO. The fit coherences were likely decreased due to the large time distance between cued measurements and the limited amount of acceptable background data.

7.2.22 Confirm Inversion Model Supports Classification (2 of 3) – Fit Location

At 29 Palms and CCR, the reliability of the AGC results depended on collecting data where the sensor was above the subsurface metallic object. The MQO was met if the fit location estimate of the subsurface item was less than or equal to 0.4-m from center of sensor for 100% of the cued measurements. At 29 Palms, the best fit in the multi-object solver for 635 of the 667 targets (or 95.2%) had a fit location offset of less than 0.4-m and achieved this MQO. Although the best match for 32 targets didn't pass the fit location test, the cued data for many of these targets included multiple fits and some of the secondary fits were within the metric. At CCR, both analysts evaluated this MQO using both single and multi-source fit locations. Based on the fit results, 100% of the cued measurements had a fit location within 0.4-m of the recorded location of the TEMTADS array center.

7.2.23 Confirm Inversion Model Supports Classification (3 of 3) – Fit Location

At CCR, the reliability of the AGC results also depended on reliably being able to classify targets at their respective location. The metric for this MQO was met if 100% of the modelled BSI locations were less than or equal to 0.25-m from their known position (x, y, z). Analysts 1 and 2 respectively met this MQO for 20 of the 28 BSIs (71.4%) and 21 of the 28 BSIs (75%). Neither analyst met the MQO, likely due to a combination of inconsistent background readings and the abundance of signal interference from the presence of immediately adjacent shallow clutter/MD (frag and fuse components).

7.2.24 Confirm Derived Features Match Ground Truth (1 of 2) – Fit Location

At 29 Palms and CCR, the reliability of the AGC results depended on reliably being able to classify targets at their respective location. The MQO at 29 Palms was met if 100% of predicted BSI positions were less than or equal to 0.25-m from their known position (x, y, z). At 29 Palms, all BSIs met this MQO. At CCR, the MQO was met if 100% of the predicted target locations of all items recovered from target locations in the training set (-1), likely TOI (1), and can't decide (2) class of the final dig list were less than or equal to 0.25-m from known position. Analyst 1 met this MQO for 80% of modeled target locations and Analyst 2 met this MQO for 66% of modeled targets; therefore, neither analyst achieved this MQO. This failure was largely due to the abundance of shallow clutter and MD recovered within the dig proximity of the primary target of concern and possibly due to the extended period between background readings after removing bad background readings.

7.2.25 Confirm Derived Features Match Ground Truth (2 of 2) – AGC results

At 29 Palms and CCR, the reliability of the AGC results depended on reliably being able to classify targets. The prioritized AGC anomaly list and dig results were used to determine whether the AGC results matched the dig results for the targets that were intrusively investigated. Not all targets were intrusively investigated at 29 Palms; therefore, this MQO could only be evaluated qualitatively. At 29 Palms, the predicted target size based on AGC qualitatively matched the size of the dig results. In addition, the 10 category 3 targets (*i.e.*, unlikely to be TOI) that were dug were correctly classified as non-TOI.

At CCR, the MQO was met if 100% of recovered object size estimates (excluding can't analyze category) qualitatively matched the predicted size. To assess this, the predicted sizes of the targets in Categories 1 (likely TOI) and 2 (can't decide) on the final submitted dig list were compared to the dig results provided by ESTCP. The size bands approximated on the dig list were based on object diameter and ranged from 0 to 50-mm (size band 1), between 50-mm and 100-mm (size band 2), and greater than 100-mm (size band 3). Of the 465 and 483 targets Analysts 1 and 2 respectively classified as class 1 (likely TOI) and class 2 (can't decide) targets on the final dig list, all items recovered from targets interpreted with diameters in size band 1 were consistent with smaller diameter objects. However, the items recovered from target locations predicted to have diameters in size band 2 consisted of both medium diameter and small diameter objects (e.g., MD, small arms, fuse components, and several small ISO80 seeds). All targets predicted to have diameters in size band 3 consisted of large munitions debris. Neither Arcadis analyst 1 met this MQO based on the relatively small items found in size band 2.

7.2.26 Validation of TOI/non-TOI Thresholds

The data reliability depends on the classification approach to correctly identify TOI and non-TOI. This MQO was met if 100% of predicted non-TOI intrusively investigated were non-TOI (*i.e.,* all TOI were correctly classified). Arcadis submitted ranked anomaly lists for CEMR and CCR to the ESTCP program office that were then scored by IDA. Because not all anomalies were intrusively investigated at 29 Palms, a ranked anomaly list was not submitted and scored. The below sections provide details on Arcadis performance of this MQO.

7.2.26.1 CEMR

Arcadis prepared a ranked anomaly list for the cued MetalMapper data and two ranked anomaly lists for the TEMTADS dataset and IDA personnel used their scoring algorithms to assess the results. Anomalies were classified as follows:

- *Category 1:* anomalies for which training labels had been requested. These anomalies were placed at the top of the dig list.
- *Category 0:* Anomalies for which Arcadis was not able to extract reliable parameters.
- *Category 1:* Anomalies that had a combined metric match to TOI greater than 0.85. These anomalies were believed to have a high likelihood of being TOI.
- *Category 2:* Anomalies that had a combined metric match to TOI between 0.8 and 0.85. Arcadis was unsure whether these anomalies were TOI or non-TOI.
- *Category 3:* Anomalies that had a combined metric match to TOI less than 0.8 or a combined metric match to Clutter greater than 0.85. These anomalies had a high likelihood of being clutter items and/or a low likelihood of being TOI. These anomalies were placed below the dig threshold.

On TEMTADS dig list A, the Arcadis analyst attempted to further reduce the number of non-TOI that required intrusive investigation by removing an additional MD cluster from the dig list (*i.e.,* classifying these anomalies as Category 3). Arcadis incorrectly classified two TOI on the MetalMapper (EL-406 and EL-332) and one TOI on both of the TEMTADS dig lists (El-1440). The following sub-sections discuss the reason for the failure to correctly classify each of these targets.

MetalMapper Results

The best matches to target EL-332 were to 2.36-inch rocket weights that were added to the clutter library. The second best, 2-component match was to a small ISO in the TOI library from Camp Butner. Further analysis of this target indicates that it had high fit metrics to ISOs for all three fit matches and would have been identified as a TOI based on the high fit metric if the clutter item had not been included in the TOI library. Target EL-406 was incorrectly classified as non-TOI; however, target EL-417, which is close to EL-406, was correctly identified as TOI. The primary reason for not classifying target EL-406 correctly is that the instrument was placed 0.51-m away from the surveyed location of the BSI.

TEMTADS Results

Target EL-1440 was incorrectly classified as non-TOI on both submitted ranked TEMTADS dig lists. On both ranked anomaly lists, the target's best match was to a 2.36-in rocket motor that was added to the clutter library. The polarization curves for this target did not exhibit normal decay (*i.e.,* betas decreasing as a function of time). Instead, the β_2 curve for the best match exhibited a relatively flat decay over the middle time gates. β_3 also quickly decayed into the noise levels. The poor decays for the secondary and tertiary betas suggest that this target had a low amplitude and the algorithm had difficulty extracting useful polarization parameters throughout the decay curve. In addition, the non-normal decay of the β_2 curve suggests there also might have been a poor background correction that caused the curve to remain relatively constant over time. Based on these observations, the analyst should have either re-performed the background correction, or only used the 1-component metric match to classify this target.

7.2.26.2 29 Palms

The number of anomalies that could be intrusively investigated at 29 Palms was restricted to approximately 40 anomalies by the U.S. Navy through whom the RI was contracted. Because not all anomalies were intrusively investigated, a full, ranked anomaly list was not submitted to ESTCP and could not be scored by IDA. Instead, Arcadis evaluated the preliminary ranked target list, the QC and QA BSIs, and the dig results for the anomalies that were TOI. Arcadis used a threshold of 0.925 as a decision statistic for the TOI stop-dig threshold. All QC and QA BSIs, and all recovered MEC were above this threshold. Because not all targets were dug during this demonstration, this analysis is only qualitative (*i.e.*, TOI that weren't investigated could be present below this threshold).

7.2.26.3 CCR

Arcadis Analysts 1 and 2 prepared ranked anomaly lists for the cued TEMTADS dataset and IDA personnel used their scoring algorithms to assess the results. **Table 7-1** presents the AGC approach Analysts 1 and 2 used Categories -1 through Category 3. All categories were placed above the stop-dig threshold except category 3. The decision statistics used were the default, weighted average of the 3-component, 2-component, and 1-component library matches in Geosoft Oasis Montaj UX-Analyze Advanced. Analysts 1 and 2 both incorrectly classified 6 TOI as non-TOI and therefore, did not achieve this MQO. **Table 7-2** presents a summary of the TOI incorrectly classified, the original decision statistic for the target ID, and a revised decision statistic after the failure was identified. Both analysts incorrectly classified a 25-mm projectile and five 37-mm projectiles.

The incorrectly classified TOI for Analyst 1 and Analyst 2 had decision statistics between 0.53 through 0.76 and between 0.42 and 0.69, respectively. These decision statistics were below the respective analyst's stop-dig threshold. The best fits included rifle grenades, 37-mm projectiles, and 40-mm projectiles. A visual inspection of the six recovered items showed that except for the item encountered at target CR-0930 (a 25-mm projectile), all the remaining targets consisted of remnants of 37-mm projectiles, and as such, were classified as MD by the dig team in the field. However, it was later determined by the site team that these items were close enough to a complete 37-mm projectile to be considered TOI for the purposes of AGC.

While 20-mm projectiles were initially included in the field verification and validate library versions of the TOI library, both analysts removed 20-mm projectiles from the TOI library for the final classification to reduce the number of false matches to clutter objects after confirming with the ESTCP Program Office that 20-mm projectiles were not TOI at CR. After failing to identify the 6 missed TOI, both analysts were re-processed; the 6 missed TOI with 20-mm projectiles included in the TOI library. **Table 7-2** shows the revised AGC results for the incorrectly classified TOI which were assigned decision statistics between 0.69 through 0.94 and 0.722 to 0.93 for analysts 1 and 2, respectively. All these would have fallen above the stop-dig threshold except Target CR-0930 for Analyst 1. Analyst 1 would have needed to include 20-mm projectiles in the TOI library and reduce the stop-dig threshold to 0.69 to correctly classify all the TOI. Reducing the stop-dig threshold to 0.69 would have significantly increased the number of non-TOI targets that required intrusive investigation to ensure all TOI were recovered.

In summary, Analysts 1 and 2 incorrectly classified the 6 TOI because 1) the 37-mm projectiles were incomplete rounds, 2) the 25-mm projectile wasn't in the TOI library, and 3) neither analyst included 20-mm projectiles in the final TOI library and the 20-mm projectile was the best match to each of the missed TOI.

Table 7-1. AGC Approach at CCR for Analysts 1 and 2

Category	Analyst 1	Analyst 2
Category -1: Training Data	Training data requested for 81 targets to evaluate clusters	Training data requested for 42 targets to evaluate clusters
Category 0: Can't Analyze	• There were no polarizabilities because the inversion did not finish; • The fit depth was unreasonable (*e.g.*, greater than 2-m bgs) • There were negative polarizabilities; • There was a poor fit coherence (*e.g.*, less than 0.8); and • Reliable polarizabilities couldn't be extracted (*e.g.*, array center to fit location greater than 0.4-m).	
Category 1: High Likelihood of being TOI	Anomalies with decision statistics greater than 0.925.	
Category 2: Analyst unsure if anomaly is TOI or non-TOI	Target with decision statistics between 0.825 and 0.925 and non-weak targets with decision statistics above 0.75.	Targets with decision statistics between 0.925 and 0.71
Category 3: High Likelihood non-TOI	Anomalies that didn't meet above criteria.	Targets with decision statistics less than 0.71

Table 7-2. Decision Statistic Comparisons for Analysts 1 and 2

Target ID	TOI Type	Initial AGC Results		Revised AGC Results	
		Decision Statistic	Best 3-Component Match	Decision Statistic	Best 3-Component Match
Analyst 1					
CR-930	25-mm projectile	0.6119	37-mm projectile	0.6925	20-mm projectile
CR-692	37-mm projectile	0.6568	Steel rifle grenade	0.8861	
CR-1089		0.5275	37-mm projectile	0.9139	
CR-198		0.6775	Steel rifle grenade	0.8899	
CR-886		0.7508	Steel rifle grenade	0.9356	
CR-1148		0.7618	40-mm projectile	0.8271	
Analyst 2					
CR-930	25-mm projectile	0.6463	37-mm projectile	0.7222	20-mm projectile
CR-662	37-mm projectile	0.6528	Steel Rifle Grenade	0.8705	
CR-1089		0.4176	37-mm projectile	0.9119	
CR-692		0.5568	37-mm projectile	0.8365	
CR-886		0.6899	Steel Rifle Grenade	0.936	
CR-1148		0.7113	37-mm projectile	0.8609	

7.2.27 Maximize Correct Classification of non-TOI

At CEMR, Arcadis evaluated the number of reduction of false alarms, or the amount of non-TOI that could accurately be classified as non-TOI. The MQO was met if more than 75% of the non-TOI items were correctly labeled as non-TOI while retaining all the TOI on the dig list. Arcadis correctly classified 59% of non-TOI at our stop dig threshold on the MetalMapper dig list and between 50% and 55% on two dig lists submitted for the TEMTADS data. The MQO was not achieved for either of these two datasets. The failure was due to several MD clutter items that were of a similar size to the small ISOs used for blind seeding. Although these clutter items were added to the TOI library, a significant number still needed to be placed above the stop-dig threshold to correctly classify TOI.

7.2.28 Minimize Number of Anomalies that Cannot be Analyzed

At CEMR, successful classification required that reliable parameters could be estimated. The MQO was met if reliable parameters could be estimated for more than 95% of the cued anomalies on the ranked anomaly list. Anomalies for which reliable parameters couldn't be estimated were placed in Category 0, or the "Can't Analyze" category. The percent of Category 0 targets were 6.82% and 7.02% for the TEMTADS and MetalMapper dig lists, respectively; therefore, this MQO was not achieved.

7.2.29 Correct Estimation of Target Parameters

At CEMR, successful classification required that input features were internally consistent and that various target parameters could accurately be estimated. The MQO was met if the estimated X, Y locations of BSIs were within 15-cm (1σ) and the estimated depths are within 10-cm (1σ). Nine of the 100 BSIs had horizontal offsets greater than 10-cm: five for the MetalMapper and four for the TEMTADS datasets. The offsets generally range from 15-cm to 21-cm; however, one target had an offset of approximately 83-cm. Another, nearby target location correctly classified the missed seed item; therefore, the dig team still would have found the item.

Six of the 100 BSIs had depths that exceeded the 10-cm metric: three MetalMapper and three TEMTADS targets. The depth differences were generally between 10- and 20-cm; however, one target had a depth difference of 39-cm. Neither the horizontal nor the depth MQO was met for all BSIs in either dataset.

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8.0 COST ASSESSMENT

This section provides cost information to aid in helping professionals involved in MR projects to reasonably estimate costs for implementation at a given site. This section is broken down into sub-sections that discuss the cost model, cost drivers, and cost benefit of the various technologies employed at the various demonstration sites.

8.1 COST MODEL

Arcadis tracked costs throughout all the ESTCP live site demonstrations and developed a simple cost model to aid professionals in the field to understand costing implications. **Table 8-1** presents the costs associated with the CEMR, 29 Palms, and CCR demonstrations. The cost models reflect all cost elements that would be required for implementing the technologies described in this report, as well as the planning, and reporting requirements. Intrusive investigation or data validation costs at 29 Palms and CCR were captured under separate contracts; therefore, the per-anomaly costs from CEMR were used to estimate what intrusive investigation would have cost at 29 Palms and CCR if intrusive investigation had been performed under this contract.

8.2 COST DRIVERS

In general, the intrusive investigation costs are the largest cost drivers on MR projects. Additional cost drivers include the following.

- **Dynamic MetalMapper Survey Costs:** The dynamic MetalMapper survey at 29 Palms was conducted in 100-ft x 100-ft grids randomly spread around the site vs. the contiguous 5 acres where dynamic MetalMapper data was collected at CEMR. The dynamic MetalMapper survey costs were approximately double those at CEMR. The increased costs were associated with the additional time required to turn the MetalMapper around at the end of each 100-ft line and lining the instrument up on the next line of data, which significantly decreased the production rate. The costs encountered 29 Palms are applicable to RIs, while the CEMR costs are applicable to removal actions.

- **Dynamic MetalMapper Processing Costs:** The dynamic MetalMapper data at 29 Palms was processed using a peak picking algorithm as well as the MMDR, or ISS method. The ISS method was approximately twice as expensive as the peak picking; however, the MMDR target positions were much more accurate and a significant number of anomalies were determined not to require cued data collection to determine they were non-TOI.

- **Intrusive investigation cost savings:** The cost savings associated with a reduced number of non-TOI can lead to a large cost savings since the intrusive investigation costs are the largest cost drivers on a MR project. Using the greatest reduction in non-TOI targets that Arcadis has accomplished to date (Pole Mountain ~ 70%), would result in an approximate 25 – 40% reduction in intrusive costs investigation costs, depending on the number of targets and the advanced EMI sensor utilized.

Table 8-1. Details of Costs Tracked during Arcadis' Live Site Demonstrations

Cost Element	CEMR		29 Palms		CCR	
	Data Tracked During Demonstration	**Estimated Costs**	**Data Tracked During Demonstration**	**Estimated Costs**	**Data Tracked During Demonstration**	**Estimated Costs**
Project Planning	Develop project-specific plans (demonstration plan and Health and Safety Plan), and general pre-planning activities.	$26,746	Develop project-specific demonstration plan, and general pre-planning activities.	$17,690	Develop project-specific demonstration plan, and general pre-planning activities.	$6,000
Mobilization	Mobilization of geophysical and UXO teams and equipment.	$58,740	Mobilization of geophysical teams and equipment, including GPS, MetalMapper, and TEMTADS. Includes 3 mobilizations. UXO team mobilizations covered under separate contract.	$63,388 Average Mobilization: $21,129	NA	NA
Site Preparation	Site Boundary Surveys; Blind Seeding; IVS setup; Test Pit Measurements; and Instrument Training	$39,067	Site Boundary Surveys; blind seeding; IVS setup; and test pit measurements.	$15,430	NA	NA
EM61-MK2 Data Collection	DGM data collection and processing of 6 acres (5 acres and 1 acre of re-collected data)	**Total Cost:** $43,430 (6 acres) Cost per Acre: $7,238	NA	NA	NA	NA
Dynamic TEMTADS Survey	Dynamic TEMTADS data collection; daily IVS and QC tests. TEMTADS rental costs are not included.	**Total Cost:** $5,761 (0.68 acres) Cost per Acre: $8,472	NA	NA	NA	NA
Dynamic MetalMapper Surveys	Dynamic MetalMapper data collection; and daily IVS and QC tests. MetalMapper rental costs are not included, but tractor costs are.	**Total Cost:** $36,803 Cost per Acre: $6,479	Dynamic MetalMapper data collection; daily IVS and QC tests. Includes MetalMapper rental costs. Does not include data processing, which is outlined below. Note, grids were non-contiguous, which significantly slowed the production rates relative to CEMR.	**Total Cost:** $50,069 Cost per acre: $14,554	NA	NA

Table 8-1. Details of Costs Tracked during Arcadis' Live Site Demonstrations (Continued)

Cost Element	CEMR		29 Palms		CCR	
	Data Tracked During Demonstration	Estimated Costs	Data Tracked During Demonstration	Estimated Costs	Data Tracked During Demonstration	Estimated Costs
Dynamic MetalMapper Processing/QC	Included above in the dynamic MetalMapper survey costs		MMPP Data Processing/QC	**Total Cost:** $10,883 Cost per acre: $3,163	NA	NA
			MMDR Data Processing/QC	**Total Cost:** $25,041 Cost per acre: $7,279	NA	NA
TEMTADS Cued Data Collection / QC	Target reacquisition; cued TEMTADS data collection; data processing and QC; and daily IVS and QC tests. TEMTADS rental costs are not included.	**Total Cost:** $68,061 (1087 anomalies)	Target reacquisition; cued TEMTADS data collection; daily IVS and QC tests. TEMTADS rental costs are not included.	**Total Cost:** $32,238 (667 anomalies)	NA	NA
		Cost per Anomaly: $62.60		Cost per Anomaly: $48.33		NA
MetalMapper Cued Data Collection/QC	Cued MetalMapper data collection; data processing and QC; and daily IVS and QC tests. MetalMapper rental costs are not included, but tractor costs are.	**Total Cost:** $46,219 (1,195 anomalies)	NA	NA	NA	NA
		Cost per Anomaly: $36.80				
Cued Data Analysis	Target parameter extraction and AGC	**Total Cost:** $18,276 (2,282 anomalies)	Data Processing and QC; target parameter extraction; AGC.	**Total Cost:** $6,722 (667 anomalies)	Data Processing and QC; target parameter extraction; AGC.	**Total Cost:** Analyst 1: $11,454. Analyst 2: $9,817. (1,491 anomalies)
		Cost per Anomaly: $8.10		Cost per Anomaly: $10.08		Cost per Anomaly: Analyst 1: $7.68. Analyst 2: $6.58

Table 8-1. Details of Costs Tracked during Arcadis' Live Site Demonstrations (Continued)

Cost Element	CEMR		29 Palms		CCR	
	Data Tracked During Demonstration	**Estimated Costs**	**Data Tracked During Demonstration**	**Estimated Costs**	**Data Tracked During Demonstration**	**Estimated Costs**
Validation Digging	Target reacquisition; intrusive investigation; intrusive results reporting; and post-dig anomaly QC.	**Total Cost:** $300,516 (1,785 anomalies)	Costs were covered under a separate contract. Provided costs are estimated based CEMR costs	**Total Cost:** $110,989 (667 anomalies)	Provided costs are estimated based on CEMR costs	**Total Cost:** $248,512 (1,492 anomalies)
		Cost per Anomaly: $166.40		Estimated Cost per Anomaly: $166.40		Estimated Cost per Anomaly: $166.40
Final Report	Develop project-specific final report	$20,000	Develop project-specific final report	$25,000	Develop project-specific final report	$20,000

8.3 COST BENEFIT

The primary driver for implementing AGC is to reduce the number of non-TOI targets that require intrusive investigation and thereby, decrease the overall costs of DoD's MMRP cost-to-complete. AGC has been shown to reduce the overall number of non-TOI digs by 60-90%. For example, Arcadis successfully reduced the number of non-TOI digs by 70% at Pole Mountain. Arcadis' analysts were able to reduce the total number of digs by approximately 40-50% at CEMR and approximately 43% at CCR. Both sites were more complicated than Pole Mountain. 29 Palms was conducted in parallel to an RI site and only a limited number of anomalies were intrusively investigated; therefore, it is not known what reduction in non-TOI could have been achieved. As shown above, the dynamic MetalMapper costs were significantly greater at 29 Palms when the grids were not contiguous and there appears to be no benefit to performing dynamic MetalMapper surveys at similar sites. **Table 8-2** provides a cost-benefit analyses for performing AGC using the costs from CEMR and 29 Palms for the dynamic EM61-MK2 surveys and cued TEMTADS. Static costs (*e.g.,* planning, reporting, and mobilization) and costs with minimal variability (*e.g.,* site preparation) are not included in the cost-benefit analysis. Each scenario is compared against performing a traditional MMRP project that includes an EM61-MK2 survey and intrusive investigation of all anomalies. Neither scenario includes performing dynamic surveys with advanced EMI sensors and using the ISS processing method.

Table 8-2 contains two scenarios:

- **Scenario 1:** Greatest cost savings associated within reducing the number of targets requiring intrusive investigation by 90%.
  - AGC Cost Savings: 46%
- **Scenario 2:** Lowest cost savings associated within reducing the number of targets requiring intrusive investigation by 70%.
  - AGC Cost Savings: 27%

Table 8-2. AGC Cost Evaluation

Cost Element	Cost per Unit	Unit	Quantity	Traditional MMRP Costs	AGC Costs
Scenario 1 – Greatest Cost Savings: 90% Anomaly Reduction					
EM61-MK2 Survey[1]	$4,000	Acres	5	$20,000	$20,000
TEMTADS Mobilization	$20,000	Lump Sum	1	$0	$22,000
Cued TEMTADS[2]	$48.33	Anomaly	2000	$0	$96,660
Classification	$10.08	Anomaly	2000	$0	$20,160
Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
Dig 10% of Anomalies	$166.4	Anomaly	200	$0	$33,280
Total:				**$352,800**	**$192,100**
Cost Savings ($):					**$160,700**
Cost Savings (%)[3]					**46%**
Scenario 2 – Low Cost Savings: 70% Anomaly Reduction					
EM61-MK2 Survey[1]	$4,000	Acres	5	$20,000	$20,000
TEMTADS Mobilization	$20,000	Lump Sum	1	$0	$22,000
Cued TEMTADS[2]	$48.33	Anomaly	2000	$0	$96,660
Classification	$10.08	Anomaly	2000	$0	$20,160
Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
Dig 30% of Anomalies	$166.4	Anomaly	600	$0	$99,840
Total:				**$352,800**	**$258,660**
Cost Savings ($):					**$94,140**
Cost Savings (%)[3]					**27%**

Notes:
1 – EM61-MK2 survey costs are estimated from other projects.
2 – Assumes an additional $750/day rental costs for the TEMTADS that was not required at 29 Palms, but would be required if a MetalMapper 2x2 was used.
3 – The cost savings presented here do not include additional costs that are anticipated to be consistent between the traditional MMRP and AGC cost estimates. These include, but are not limited to geophysical and intrusive investigation team mobilization costs, project management costs, and MEC demolition costs.

9.0 IMPLEMENTION ISSUES

The field conditions encountered at each site demonstrations presented unique challenges. Varying lessons were learned from the field efforts, as well as in-processing the data and performing AGC. Some of the issues encountered during the field (e.g., the TEMTADS only had 2 wheels at CEMR) have subsequently been fixed and are not documented below. The following sub-sections document the field, data processing, and AGC issues encountered during the life of this contract.

9.1 FIELD IMPLEMENTATION ISSUES

Arcadis collected dynamic and cued MetalMapper and TEMTADS data at CEMR, dynamic MetalMapper data at 29 Palms, and cued TEMTADS data at 29 Palms. Cued data was analyzed at CEMR, 29 Palms, and CCR. The below are the field and data processing implementation issues encountered during the Live Site Demonstrations.

- **TEMTADS Data Acquisition**
  - The TEMTADS was somewhat difficult to move across the various demonstration sites due to the low instrument height above ground surface. This issue was most pronounced at CEMR where the instrument consistently got caught on short corn stalks that were present on elevated corn rows while operating the instrument in dynamic mode. On future sites, it might be better to either perform the dynamic surveys with an instrument with a greater height above the ground surface (*e.g.,* EM61-MK2) or put the TEMTADS on a sled on the ground surface. The MetalMapper did not have a similar issue with the corn stalks at CEMR.
  - The hot swap capability of the battery is an advantage because battery life is relatively short; however, emplacing the batteries under the CPU can be difficult due to the tight space afforded. A design allowing side access to the battery compartments would be a benefit.
- **MetalMapper Data Acquisition**
  - The major issue with MetalMapper data acquisition relates to its relative lack of mobility and the need to use a tow or push vehicle to move it across the site. At CEMR, Arcadis used a wheeled, boom forklift to move the MetalMapper. This unit provided shelter from the environment and protection for the non-ruggedized computer, however, the forklift lost traction in soft soil (e.g., after a rain event). At 29 Palms, the wheeled forklift was unable to navigate in the soft sand. Instead, a small tracked skid steer was used. This unit had a partially enclosed cab, which provided some protection from the elements for the operator and computer, and it navigated successfully in the sand; however, the tracks dug in over six inches during sharp turns, posing a safety hazard in the production area (*i.e.,* it could have dug up MEC during a turn). Additionally, the tracks of the skid steer induced severe vibration on the central processing unit (CPU). The CPU was isolated with foam padding, but still shook enough that the video card and various connections became intermittent by the conclusion of the dynamic acquisition.

- Using the MetalMapper during an RI with randomly placed grids proved inefficient due to the significant amount of time required to turn the instrument at the end of each line of the 100-ft x 100-ft grids. This extra time to turn the instrument resulted in significantly reduced production rate and increased costs. For dynamic surveys in randomly placed grids, it is much more cost effective to use a man portable sensor such as the TEMTADS or EM61-MK2.

9.2 DATA PROCESSING AND AGC IMPLEMENTATION ISSUES

Arcadis didn't collect the TEMTADS data at CCR; therefore, we did not encounter implementation issues associated with data collection. However, based on our analysis of the background data collected by URS, it's apparent that there was significant background variation at individual background locations. This could have been due to there being metallic objects close to the background location and/or the TEMTADS not being placed back on the respective background locations in a consistent manner (*e.g.,* could have been slightly off in location and/or orientation). Due to the background variation, each analyst found it challenging to determine the trade-off point between removing background data and keeping enough background measurements to level the data. Each analyst removed a significant number of background data prior to leveling cued data; however, each then needed to level cued data with background data points that were up to 6 hours from the cued data. More rigorous background QC procedures have been developed and demonstrated on other sites, such as Arcadis' 29 Palms Demonstration (Arcadis, 2015). These procedures should continue to be used and updated as needed to ensure that high quality background data is collected.

In addition, the ESTCP program office informed Arcadis that 20mm projectiles were not a TOI at CCR; therefore, both analysts removed 20-mm projectiles from the TOI library to minimize the number of small clutter that needed to be dug. No 20-mm projectiles were found, however, the TOI missed by both analysts included a 25-mm projectile and partial 37-mm projectiles that best fit to 20-mm projectiles. In future demonstrations or on production sites, the data analysts should request further information about whether partial projectiles that may not contain an explosive hazard are considered TOI and perform additional analyses to ensure that small non-hazardous MD items considered TOI are recovered.

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